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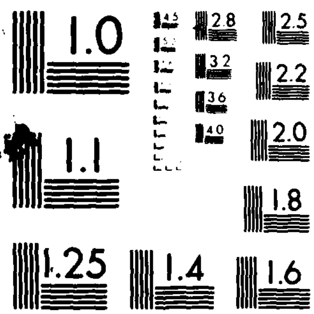

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Potential construction productivity improvement through the use of technological factors is assessed. Data was gathered through solicitation of information from top, corporate level construction managers among the important owner companies and the largest 400 American contractors and design firms.

Technological factors covered consisted of construction categories and construction indicators of potential productivity improvement.

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A Masters Report (Thesis) submitted to the University of Texas at Austin in partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering

CONSTRUCTION PRODUCTIVITY IMPROVEMENT
THROUGH TECHNOLOGICAL FACTORS

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CONSTRUCTION PRODUCTIVITY IMPROVEMENT
THROUGH TECHNOLOGICAL FACTORS

BY

STEPHEN MICHAEL SHEPPARD, M.S.B.A.

REPORT

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for the Degree of

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December, 1981

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The construction technology study could not have been conducted without valuable assistance from executives active in today's construction industry. Appendix B lists the companies which contributed information.

Sincere appreciation is given to Mr. Warren Bellows who helped to evaluate the research questionnaire used in the study.

The preliminary efforts of Doctor Richard Tucker helped formulate the questionnaire and distribution sequence.

The support of John Rickard and the efforts of Bryan Tucker, both fellow graduate research assistants, helped complete my endeavors. John drafted many of the figures appearing in the study results. Bryan assisted with computer data reduction and analysis of the results.

Most importantly, I appreciate the duty time given to me by the Department of the Army to complete my research.

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CHAPTER 1. RELATED CONSTRUCTION TECHNOLOGY STUDIES

1.1. Former Questionnaire Efforts

A survey of knowledgeable owners, contractors, and designers is a rapid, efficient tool for gathering construction information. In the past, the survey format has been used successfully in related construction information endeavors.

The Associated General Contractors of America, through its Education and Research Foundation, mailed questionnaires to 1200 contractor members to assess research needs in the construction industry and to identify appropriate procedures for research initiation. The 1975 questionnaire had 148 responses which contributed greatly to AGC's efforts. The responses were analyzed at the University of Texas at Austin (6).

A survey of the top 400 Engineering News Record contractors was conducted in 1979 by the Illinois Institute of Technology Research Institute to assess areas of productivity improvement in construction. Ninety-nine of 400 surveys were returned, providing contractor input on productivity improvement potential and contractor willingness to support improvement activities (3).

1.2. CICE

Prominent project owners and contractors agree that one of the basic factors contributing to ever increasing construction expense is the low rate of U.S. technological advance. Evidence also exists that American technological advance is not as progressive as that of foreign construction competitors. Technological advance could be the most important contributor to future construction productivity increase.

The Construction Industry Cost Effectiveness Project (CICE) is a ten year work/research program designed to modernize and upgrade the U.S. construction industry. CICE recognizes the importance of technological advance and wishes to make the U.S. competitive in construction progress. Once significant advance is realized, CICE wants to sustain the rate of advance.

1.3. Construction Technology Study Area

Within the framework of the CICE effort to achieve technological advancement exists the Construction Technology Study Area. The members of the study area initially assessed current conditions and causes for deficient technological development. The members concluded the assessment in 1980 by recommending a study program with three main parts (2):

1. Formation of a task force to be taken from experts active in modern construction with the mission of developing a formal survey of construction technology needs.

2. Execution of a series of detailed studies to formulate research and development programs and future efforts of the study group.

3. Critique and finalization of results of the other parts at a construction technology conference.

Currently, two teams are working on part 2 studies. Team 1 is studying the integration of planning, design, and construction. Team 2 is investigating construction research and development.

1.4. University of Texas Endeavors

The University of Texas research team was a subdivision of Team 2. The research team was contracted by CICE to determine areas of technological need and advancement potential (5). Its efforts were organized into two parts. Part 1 involved a questionnaire which solicits identification of specific problem areas from contractors, project owners, and design firms. Part 1 questionnaires also provided guidance for a subsequent, more detailed second part which was conducted at construction project level. Part 2's purpose was to obtain information from people close to actual construction activities and also to explore technology transfer opportunities.

The ensuing report describes and analyzes the efforts of the research team in part 1 efforts.

1.4.1. Scope of Studies

The technological research team concentrated on technological aspects of the modern construction effort. Hardware, building materials, tools, systems, and mechanical improvements were within the limits of the research. The part 1 study utilized expert opinions of modern construction managers to identify areas of construction effort which would most benefit from further technological research.

The part 1 questionnaire also collected data concerning uses of integrated construction technology. The results were sent to another CICE study and are not included in this report.

1.4.2. Objectives of Part 1 Research

The main objective of part 1 research was to prioritize potential technological areas for subsequent detailed research by the research team which would follow in part 2 studies. Opinions of corporate level construction managers were solicited through the use of mailed questionnaires. Owner companies, contractors, and design firms were asked to provide input. Selection criteria included:

1. Listing of contractors in the current ENR 400.

2. Representative contractors with expertise in Buildings, Light and Heavy Industrial projects, and Power Generation construction.

3. Design firms working in all divisions of contruction covered in the study.

4. National geographic distribution.

In addition to technological potential data, added information from the part 1 questionnaire included:

1. Current use of integrated construction technology data (to be used by another CICE study group).

2. Solicitation of construction sites available during July-October, 1981, for part 2 investigations.

3. Other relevant comments helpful to the research being performed.

CHAPTER 2. QUESTIONNAIRE AND RESEARCH

2.1. Selection of the Research Instrument

The University of Texas research team used a questionnaire similar in concept to the previously employed surveys. The target audience was expanded to include prominent project owners with engineering staffs and design firms as well as ENR 400 contractors. A wealth of construction information existed in owner and design firms which was of great value to the research efforts.

The research team felt that a short, succinct questionnaire designed to be time efficient was the best information tool to use under current conditions in the construction environment. During the part 1 research period, the construction world was flooded with questionnaires, work studies, interview sessions, and other information efforts. With such an avalanche of activity, the information collecting done by the research group needed to be done quickly and efficiently. The survey was designed to require 20 minutes to complete. Each section of the questionnaire was clearly explained in a brief, concise manner. Instructions were supplemented with telephonic explanations. Coordination was made with company representatives prior to distribution.

The questionnaire developed is Appendix A.

Corporate level constructors were selected to complete the questionnaires for two reasons:

1. Corporate constructors maintain contact with the full gamut of projects handled by their companies.

2. Corporate constructors have experience in their backgrounds which was reflected in their answers.

2.2. Questionnaire Design

The questionnaire was not designed as a statistical study. Its purpose was to obtain information and opinions representative of expertise present in modern construction.

The first three questions asked individual addresses, background experience, and questions which would categorize and adjust raw answers given in question 5.

Question 2 described the project used as a frame of reference for further answers. The question described the project in terms of type of construction division, cost, labor force size and composition, and union affiliation of labor used.

Question 3 gave cost breakdowns of the construction categories used in question 5.

Question 4 was the integrated construction technology question used by the other study group.

Question 5 was the central question of the survey. It asked the questionnaire recipient to rate the named construction categories to determine their potential for technological improvement based on selected indicators of construction category effectiveness.

Detailed Description

Question 2 solicited background information on projects used by the questionnaire respondents as frames of reference for answers in the rest of the questionnaire. The respondent was asked to:

1. Classify the projects as most typically (1) Buildings (2) Light Industrial (3) Heavy Industrial or (4) Power.

2. Give the typical project construction cost.

3. List the maximum size of the typical project's work force.

4. Give the percentage of projects that were union.

5. List the craft makeup of the work force as a percentage of the total workers used. The following crafts were submitted for respondent consideration.

a. Boilermakers
b. Carpenters
c. Cement Finishers
d. Electricians
e. Equipment Operators
f. Insulators
g. Instruments
h. Ironworkers
i. Masons
j. Millwrights
k. Laborers/Helpers
l. Painters
m. Pipefitters
n. Riggers
o. Roofers
p. Teamsters
q. Welders
r. Other crafts as given by respondent

The cost question, question 3, asked for costs associated with the typical projects described in the background question. The respondent was asked to estimate the direct construction costs that were associated with constructior categories given. The costs were expressed as a percentage of the total typical project cost.

The construction categories consisted of the following construction work processes:

1. Civil categories subdivided into earthwork, foundations, structure, enclosure skin, interior finishing, and roofing
2. Mechanical categories, subdivided into piping, plumbing, vessels, hvac, and mechanical equipment
3. Special equipment installation
4. Electrical
5. Instrumentation
6. Insulation
7. Coatings and paintings
8. Fireproofing/fire protection

The selected construction categories were designed to account for all direct construction costs in commonly accepted, clear cut cost centers, enabling respondents to divide and list costs accurately.

Question 5 was the technological improvement question central to the questionnaire. Each category of construction was rated on a scale of 1 through 10 with 10 indicating the highest priority area for technological improvement. The ratings were based on construction indicators. The ratings resulted in exact data reduction for relative comparisons between construction categories and construction indicators.

The indicators were chosen for conciseness, ease of understanding and response brevity. The indicators were focal points of technological improvement potential within the scope of the study. An attempt was made to cover every aspect of improvement potential for a project with clearly understood and commonly accepted terms.

The construction indicators used were:

1. Difficulty in estimating costs.
2. Sensitivity to timeliness and quality of design.
3. Necessary lead time for scheduling.
4. Problems in obtaining proper materials.
5. Unplanned rework on typical projects.
6. Requirement for the most communications between engineering and construction teams.
7. Problems in handling materials and their distribution.
8. Sensitivity of prefabrication tolerances and accuracy.
9. Number of different crafts required.
10. Dependence on foreman competence.
11. Craftsman skill needed to perform operation.
12. Required specialized tools and equipment for construction.
13. Necessary coordination with support crafts.
14. Most wasted time among craftsmen.
15. Wasted time waiting for inspections.

Question 6 asked for sites available for part 2 investigations. When suitable sites were listed by the respondents, the research team contacted the site managers to arrange visits. Question 6 also solicited any added information or helpful suggestions to the research being conducted.

2.3. Data Reduction

2.3.1. Background Information

The research group divided questionnaires returned into four construction divisions according to the respondent answer to part A of the background question. If more than one answer was selected in part A, the research team used intuitive judgment in selecting the division in which the respondent's job experience indicated he was most familiar. His answers would most typlify that construction division. The construction divisions were:

1. Buildings
2. Light Industrial
3. Heavy Industrial
4. Power

In determining typical project costs within each division, the researchers averaged all answers given to determine one typical project cost for each division. Answer choices listed a range of values for each selection. The research group used the following discrete values during project cost determinations:

Choice	Discrete Assumed Cost
1. Less than $10 million	$8 million
2. 10 - 50 million	$30 million
3. 50 - 100 million	$70 million
4. 100 - 500 million	$300 million
5. Greater than 500 million	$700 million

The procedure was inaccurate for construction divisions with very few returned surveys. Wide ranges of potential error were associated with each assumed discrete value.

Similiarly, the size of the peak work force for each construction division was averaged using discrete values for each work force range given.

Choice	Discrete Assumed Number
1. Less than 100	70
2. 100 - 500	300
3. 500 - 1000	700
4. Greater than 1000	2000

The typical percentages of projects which were union were also calculated with average percentages. Assumed discrete values were needed in two of the choices.

Choice	Discrete Assumed Percentage
1. 0%	0%
2. 1 - 50%	25%
3. 50 - 99%	75%
4. 100%	100%

The labor makeup of the typical project within each division was profiled by averaging the figures for each craft and showing the average values obtained as the typical project labor makeup. Any craft with no answer was counted as zero in the overall averaging. As with the other parts of the background question, craft profiles were calculated for each of the construction divisions. If other crafts were written in addition to the standard selections available, the write-ins were included in the averaging process.

2.3.2. Cost Information

A procedure identical to that used for craft profiles was used in cost profiles for the typical project in each construction division. Intuitive judgment was used in cases where civil or mechanical costs were not divided between the subdivisions, or where costs listed separately by the respondent as not included in the given categories, were in fact, part of the categories listed. As with the labor profiles, a cost profile was calculated for each of the four construction divisions.

2.3.3. Technological Improvement

Basic Averages

On each questionnaire, each category of construction had listed for it in a vertical direction 15 answers ranging in value from 1 through 10. All blanks were to be answered unless the category of construction did not apply to the typical project used as a frame of reference for that particular questionnaire.

Each of the answers for each of the 17 categories was averaged from all answers given for a particular construction division. If the answer spaces were blank, they were not included in the averaging process.

Individual Construction Category Potential

The 15 vertical average numbers associated with each construction category were then summed and an average value was calculated from the summation. Each resultant double average number for each category represented the potential of that construction category for improvement with respect to the construction indicators. Results were kept separate for each construction division.

Individual Construction Indicator Potential

The same calculations took place in the horizontal direction. The 17 average numbers associated with each construction indicator were summed and an average was taken from the summation. The resultant number for each indicator represented the potential of that construction indicator for improvement with respect to each category.

CHAPTER 3. QUESTIONNAIRE RESULTS

3.1. Questionnaires Returned

A total of 133 questionnaires were returned representing input from 36 different companies. Major contributors included Daniel Construction Company, Dow Chemical, and Texaco Petroleum.

The questionnaires were grouped according to type of company represented.

1. Contractor Firms - 68 surveys.
2. Owner Firms - 54 surveys.
3. Design Firms - 11 surveys.

The questionnaires were also grouped according to the construction division to which the answers pertained. The number of surveys for each division comprised the data base from which further analysis was performed. The totals returned by construction division (size of data base) are summarized:

1. Buildings - 8 surveys.
2. Light Industrial - 16 surveys.
3. Heavy Industrial - 68 surveys.
4. Power - 36 surveys.
5. Composite - 5 surveys.

Information in the composite surveys was applied where relevant to the other construction divisions. The composite surveys themselves did not constitute another data group.

3.2. Project Profiles and Costs

The background information and cost information from questions 2 and 3 of the survey are outlined in Table 111-1. The table lists for each division:

1. Number of surveys in the data base.
2. Average project cost.
3. Average peak work force.
4. Average percentage of projects that were union.
5. Average labor percentage makeup by craft.
6. Average percent of direct construction costs associated with each construction category.

3.3. Technological Improvement Ratings

The basic average numbers for each answer in question 5 are listed in Table 111-2. Also listed are potential numbers of each construction category for improvement with respect to the construction indicators. They are the vertical double averages at the bottom of each page of Table 111-2.

Finally, the potential numbers of each construction indicator for improvement with respect to the construction categories are included. They are the double horizontal averages in the vertical right hand margins of each page of Table 111-2.

Table III-1a

Typical Project Profile - Buildings - Based on 8 surveys returned.

1. Average Project Cost - $25.2 million
2. Average Peak Work Force - 300
3. Average Percent of Projects that are union - 61%
4. Average Labor Percentage Makeup by Craft

Boilermakers	1%	Millwrights	1%
Carpenters	16%	Labors/Helpers	17%
Cement Finishers	7%	Painters	4%
Electricians	11%	Pipefitters	9%
Equipment Operators	4%	Riggers	1%
Insulators	1%	Roofers	2%
Instrument	1%	Teamsters	1%
Ironworkers	14%	Welders	1%
Masons	4%	Others	5%

5. Average percent of direct construction costs associated with each construction category.

Civil	
Earthwork	4.8%
Foundations	3.3%
Structure	26.9%
Enclosure Skin	15.2%
Interior Finishing	11.6%
Mechanical	
Roofing	2.1%
Piping	3.4%
Plumbing	2.2%
Vessels	2.0%
HVAC	6.5%
Mechanical Equip.	5.4%
Special Equipment Installation	1.4%
Electrical	8.5%
Instrumentation	1.6%
Insulation	.8%
Coatings and Painting	2.0%
Fireproofing/Fire Protection	2.0%

Table III-1b

Typical Project Profile - Light Industrial - Based on 16 surveys rtnd.

1. Average Project Cost - $118.6 million
2. Average Peak Work Force - 600
3. Average Percent of Projects that are union - 69%
4. Average Labor Percentage Makeup by Craft

Boilermakers	1%	Millwrights	3%
Carpenters	14%	Labors/Helpers	14%
Cement Finishers	4%	Painters	3%
Electricians	10%	Pipefitters	14%
Equipment Operators	5%	Riggers	1%
Insulators	2%	Roofers	3%
Instrument	3%	Teamsters	3%
Ironworkers	9%	Welders	2%
Masons	6%	Others	3%

5. Average percent of direct construction costs associated with each construction category.

Civil	
Earthwork	4.3%
Foundations	7.2%
Structure	17.2%
Enclosure Skin	7.0%
Interior Finishing	8.5%
Mechanical	
Roofing	3.9%
Piping	11.6%
Plumbing	3.7%
Vessels	1.4%
HVAC	8.4%
Mechanical Equip.	6.0%

Special Equipment Installation 5.7%

Electrical 11.3%

Instrumentation 2.1%

Insulation .9%

Coatings and Painting 1.9%

Fireproofing/Fire Protection 2.5%

Table III-1c

Typical Project Profile - Heavy Industrial - Based on 68 surveys rtnd.

1. Average Project Cost - $188.1 million
2. Average Peak Work Force - 896
3. Average Percent of Projects that are union - 50.9%
4. Average Labor Percentage Makeup by Craft

Boilermakers	2%	Millwrights	4%
Carpenters	8%	Labors/Helpers	10%
Cement Finishers	2%	Painters	2%
Electricians	18%	Pipefitters	22%
Equipment Operators	5%	Riggers	2%
Insulators	4%	Roofers	1%
Instrument	5%	Teamsters	2%
Ironworkers	7%	Welders	4%
Masons	1%	Others	1%

5. Average percent of direct construction costs associated with each construction category.

<u>Civil</u>	
Earthwork	3.3%
Foundations	7.5%
Structure	8.2%
Enclosure Skin	1.7%
Interior Finishing	1.6%
<u>Mechanical</u>	
Roofing	1.1%
Piping	23.9%
Plumbing	1.5%
Vessels	7.3%
HVAC	2.3%
Mechanical Equip.	9.9%

<u>Special Equipment Installation</u> 3.0%

<u>Electrical</u> 15.0%

<u>Instrumentation</u> 6.4%

<u>Insulation</u> 3.8%

<u>Coatings and Painting</u> 2.1%

<u>Fireproofing/Fire Protection</u> 1.4%

Table III-1d

Typical Project Profile - Power - Based on 36 surveys returned.

1. Average Project Cost - $466.6 million
2. Average Peak Work Force - 1635
3. Average Percent of Projects that are union - 81.3%
4. Average Labor Percentage Makeup by Craft

Boilermakers	11%	Millwrights	3%
Carpenters	9%	Labors/Helpers	13%
Cement Finishers	1%	Painters	2%
Electricians	15%	Pipefitters	18%
Equipment Operators	7%	Riggers	0% (.3%)
Insulators	2%	Roofers	1%
Instrument	1%	Teamsters	2%
Ironworkers	10%	Welders	1%
Masons	1%	Others	3%

5. Average percent of direct construction costs associated with each construction category.

<u>Civil</u>

Earthwork	6.2%
Foundations	10.4%
Structure	9.7%
Enclosure Skin	1.8%
Interior Finishing	2.2%

<u>Mechanical</u>

Roofing	.8%
Piping	16.1%
Plumbing	1.4%
Vessels	3.9%
HVAC	2.9%
Mechanical Equip.	18.5%

<u>Special Equipment Installation</u> 5.3%

<u>Electrical</u> 14.1%

<u>Instrumentation</u> 2.9%

<u>Insulation</u> 1.6%

<u>Coatings and Painting</u> 1.6%

<u>Fireproofing/Fire Protection</u> .6%

TABLE III- 2a Buildings Data Base

Question 5 Results

	CONSTRUCTION CATEGORY																	
	CIVIL					MECHANICAL						OTHERS						
Rate the work categories in terms of:	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection	--- Double Horizontal Averages
a. DIFFICULTY IN ESTIMATING COSTS	5.6	2.3	3.8	4.5	4.5	4.8	4.5	4.3	4.3	3.8	4.0	3.3	4.5	3.5	4.5	5.3	4.8	4.2
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN	5.3	4.8	6.3	7.5	8.0	6.4	8.8	7.8	9.3	7.5	8.0	8.0	8.5	8.3	7.0	7.3	6.5	7.4
c. NECESSARY LEAD TIME FOR SCHEDULING	3.0	4.0	4.0	7.3	6.8	3.6	5.8	6.0	8.0	6.0	6.0	7.3	7.5	8.3	4.3	4.3	3.3	5.6
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)	3.8	2.3	3.0	5.5	2.8	5.4	4.5	4.3	7.3	7.0	7.3	6.0	5.0	6.0	5.3	4.3	4.0	4.9
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS	4.7	4.0	3.3	3.7	4.0	4.3	6.3	6.7	6.5	4.3	5.3	5.5	5.3	6.3	6.3	7.3	3.7	5.2
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS	4.3	4.8	5.0	7.0	5.8	5.2	6.5	5.3	6.7	6.0	6.5	7.3	6.8	7.0	4.5	5.3	3.8	5.7
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION	4.3	1.3	4.0	6.7	6.0	5.7	6.7	6.4	7.7	5.7	7.3	8.7	7.0	7.0	7.3	5.3	7.7	6.2
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY	3.5	3.3	4.8	6.5	6.5	4.0	6.8	5.5	8.3	5.8	7.3	7.0	6.3	7.8	5.3	6.8	4.3	5.8
i. NUMBER OF DIFFERENT CRAFTS REQUIRED	2.3	3.8	3.0	2.0	2.8	2.5	3.3	3.0	3.7	4.0	4.5	6.7	4.0	6.0	3.8	4.5	2.8	3.7
j. DEPENDENCE ON FOREMEN COMPETENCE	6.8	6.3	6.0	7.0	5.8	6.8	6.3	6.0	4.0	7.3	7.0	6.7	7.3	7.3	6.3	6.8	6.3	6.4
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION	8.5	6.5	8.0	8.4	7.3	9.2	7.8	7.8	8.0	7.8	7.0	7.3	6.3	7.3	7.3	8.5	7.0	7.6
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION	4.5	3.3	5.0	4.8	6.3	5.8	5.5	5.5	6.3	5.3	6.3	5.7	7.0	7.3	5.3	5.3	5.8	5.6
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)	4.3	4.3	5.0	5.8	6.8	3.0	4.3	4.5	3.3	5.0	6.0	4.7	5.0	5.5	5.8	6.5	5.0	5.0
n. MOST WASTED TIME AMONG CRAFTSMEN	4.3	2.8	4.5	6.5	5.3	3.3	4.8	4.3	4.0	4.5	6.8	7.0	4.0	6.5	5.0	5.0	4.8	4.9
o. WASTED TIME WAITING FOR INSPECTIONS	4.8	3.8	3.5	2.3	3.5	4.0	4.5	5.0	5.0	5.3	5.0	7.3	6.5	5.0	4.8	4.8	3.3	4.6
Double Vertical Averages -----------	4.6	3.8	4.6	5.7	5.4	4.9	5.7	5.5	6.2	5.7	6.3	6.6	6.1	6.6	5.5	5.8	4.8	

TABLE III-2b Light Industrial Data Base

Question 5 Results

CONSTRUCTION CATEGORY

Rate the work categories in terms of:	CIVIL					MECHANICAL						OTHERS						
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection	
a. DIFFICULTY IN ESTIMATING COSTS	3.9	3.1	3.3	2.7	3.4	3.1	5.5	3.5	4.4	4.9	5.9	7.6	6.5	7.4	3.9	4.1	3.4	4.5
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN	3.6	4.4	4.9	4.0	4.6	4.7	5.4	3.4	4.8	5.3	5.9	7.3	6.3	7.2	3.6	4.1	3.6	4.9
c. NECESSARY LEAD TIME FOR SCHEDULING	4.7	4.9	6.1	4.5	4.5	4.3	5.9	4.7	5.8	5.5	7.0	7.6	6.6	6.8	3.4	3.2	3.9	5.2
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT— NOT DESIGN)	1.8	1.9	3.3	3.4	3.6	3.8	4.4	3.2	4.6	4.4	6.0	6.5	5.1	6.0	3.4	2.9	2.9	4.0
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS	2.4	2.4	2.9	2.4	3.6	3.4	4.7	3.1	2.5	4.8	4.8	4.9	4.6	5.2	2.8	2.6	2.1	3.5
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS	2.9	4.5	4.8	3.4	4.8	3.3	5.5	3.6	4.0	5.9	5.7	7.6	6.1	5.9	3.5	3.6	2.9	4.6
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION	1.3	2.5	3.9	2.8	3.4	3.1	4.4	2.9	4.0	5.0	5.6	6.1	4.9	4.9	3.5	2.0	2.1	3.7
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY	1.6	2.8	5.9	5.1	3.8	2.9	6.5	3.9	6.3	5.8	6.9	7.9	4.8	5.1	2.3	2.1	2.5	4.5
i. NUMBER OF DIFFERENT CRAFTS REQUIRED	1.6	3.1	3.1	2.6	4.4	2.2	2.4	1.9	2.4	3.1	3.5	4.8	2.3	3.1	1.5	1.6	1.6	2.7
j. DEPENDENCE ON FOREMEN COMPETENCE	3.8	5.9	5.8	5.6	6.1	6.6	7.1	5.7	5.5	6.6	6.9	7.9	7.2	7.8	4.8	4.8	4.6	6.0
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION	3.1	4.5	5.0	5.3	4.9	4.8	6.1	4.7	5.4	5.4	5.9	6.6	6.3	7.5	4.2	4.6	4.0	5.2
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION	4.3	3.2	4.0	3.8	3.6	3.8	4.5	3.8	4.8	4.8	5.5	6.5	4.7	5.2	2.5	2.7	3.1	4.2
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)	2.2	3.1	4.1	4.2	4.6	3.9	5.7	4.6	4.5	5.1	4.7	5.9	5.5	5.9	4.2	3.9	3.5	4.4
n. MOST WASTED TIME AMONG CRAFTSMEN	1.8	3.6	3.4	3.6	4.3	3.8	6.2	4.9	4.2	4.9	5.5	5.5	5.1	4.9	3.5	3.6	2.8	4.2
o. WASTED TIME WAITING FOR INSPECTIONS	2.4	3.1	2.7	2.2	2.6	3.8	4.8	4.4	4.0	4.4	4.9	5.1	4.8	5.5	2.3	2.4	2.4	3.6
	2.8	3.5	4.2	3.7	4.1	3.8	5.3	3.9	4.5	5.1	5.7	6.5	5.4	5.9	3.3	3.2	3.0	

TABLE III-2c Heavy Industrial Data Base

Question 5 Results

CONSTRUCTION CATEGORY

Rate the work categories in terms of:	CIVIL					MECHANICAL						OTHERS						
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection	
a. DIFFICULTY IN ESTIMATING COSTS	3.2	2.6	3.2	2.9	3.9	2.6	6.0	3.9	3.6	4.6	5.0	6.5	5.5	6.0	3.9	3.7	3.7	4.2
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN	3.4	4.2	4.7	3.4	3.6	3.1	7.0	4.2	5.4	5.1	6.4	6.2	6.7	7.3	3.9	3.4	3.4	4.8
c. NECESSARY LEAD TIME FOR SCHEDULING	2.8	3.8	4.5	3.7	3.1	3.4	6.4	4.4	6.2	5.2	6.5	6.4	6.1	6.6	3.8	3.1	3.2	4.7
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)	1.7	2.1	3.3	3.4	3.2	2.6	5.6	3.0	4.4	3.8	5.1	5.1	5.1	5.6	2.9	2.5	2.2	3.6
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS	1.9	2.4	3.7	2.2	2.5	2.4	6.3	2.7	2.9	3.2	3.7	4.3	4.6	5.1	2.7	2.3	2.0	3.2
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS	2.3	3.8	4.3	2.6	2.8	2.2	7.0	2.9	3.8	4.0	5.4	6.3	6.5	6.4	2.6	2.6	2.7	4.0
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION	1.5	2.1	3.4	3.0	2.5	2.2	6.1	3.0	3.7	3.0	4.3	4.4	4.7	4.9	3.2	2.3	2.1	3.3
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY	1.3	2.6	5.0	2.9	2.3	1.9	7.0	3.0	5.8	3.4	6.2	6.5	3.5	4.0	2.3	1.8	2.2	3.6
i. NUMBER OF DIFFERENT CRAFTS REQUIRED	1.7	3.2	2.6	2.1	3.3	1.9	3.5	2.2	3.1	2.7	4.1	4.6	2.6	3.3	1.8	1.7	1.8	2.7
j. DEPENDENCE ON FOREMEN COMPETENCE	3.3	5.1	5.1	4.2	4.4	4.3	7.3	4.8	4.9	5.0	6.5	7.0	7.0	7.4	4.3	3.9	3.8	5.2
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION	3.3	3.9	4.6	4.0	4.4	3.5	6.9	5.2	5.1	5.0	6.3	6.4	6.6	7.1	3.8	3.8	3.8	4.9
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION	4.1	3.1	3.6	3.6	2.9	2.9	5.1	3.4	4.2	3.6	5.0	6.2	4.6	5.1	3.0	2.9	3.1	3.9
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)	1.7	2.9	3.4	3.0	3.0	2.6	6.5	3.8	4.4	4.1	5.1	5.4	5.1	5.2	4.5	3.5	3.3	4.0
n. MOST WASTED TIME AMONG CRAFTSMEN	1.8	3.6	3.1	2.8	3.3	2.8	6.6	4.2	3.8	3.5	5.2	5.9	5.4	5.2	3.8	2.9	2.9	3.9
o. WASTED TIME WAITING FOR INSPECTIONS	2.6	3.1	2.8	1.9	2.0	2.3	4.9	3.7	3.6	3.1	4.6	4.5	3.9	4.5	2.5	2.2	2.7	3.2
	2.4	3.2	3.8	3.0	3.2	2.7	6.1	3.6	4.3	4.0	5.3	5.7	5.2	5.6	3.3	2.8	2.9	

TABLE III-2d Power Data Base

Question 5 Results

CONSTRUCTION CATEGORY

Rate the work categories in terms of:	CIVIL					MECHANICAL						OTHERS						
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Instal	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection	
a. DIFFICULTY IN ESTIMATING COSTS	3.3	2.5	2.5	1.7	2.9	2.2	5.8	3.7	3.2	4.2	4.7	5.6	5.4	5.3	4.0	3.8	3.8	3.8
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN	3.8	5.2	4.2	3.3	3.1	3.0	7.4	5.4	5.2	6.2	6.5	7.0	7.2	7.2	4.1	3.5	3.4	5.0
c. NECESSARY LEAD TIME FOR SCHEDULING	3.1	4.3	4.5	3.4	3.3	2.5	6.7	4.3	5.2	5.9	6.3	6.7	6.2	7.0	3.7	2.7	2.6	4.6
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT— NOT DESIGN)	1.9	1.8	2.4	2.8	2.7	2.0	5.3	3.4	4.3	4.4	5.2	5.2	4.7	6.0	3.3	2.8	3.0	3.6
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS	2.5	3.6	3.0	2.7	2.6	3.0	6.2	3.7	2.8	4.8	3.8	3.3	5.6	5.8	3.4	2.6	2.9	3.7
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS	2.7	3.5	2.8	2.1	2.8	3.8	6.8	4.0	4.3	5.8	5.2	5.2	6.6	7.1	3.3	2.5	2.8	4.2
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION	2.1	2.7	2.9	2.4	2.8	2.3	5.7	3.5	3.6	4.4	4.5	4.7	5.2	4.9	2.9	3.2	2.5	3.5
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY	1.3	3.0	4.6	2.9	3.3	2.5	6.8	3.1	5.2	4.4	6.2	5.6	4.2	4.5	2.6	2.6	2.2	3.8
i. *NUMBER OF DIFFERENT CRAFTS REQUIRED*	1.9	4.3	2.8	1.8	3.5	2.1	3.4	2.5	2.7	3.2	3.7	4.1	2.9	3.4	2.7	1.8	2.0	2.9
j. DEPENDENCE ON FOREMEN COMPETENCE	4.3	5.2	5.0	4.2	4.2	3.9	6.5	5.0	4.9	5.8	6.0	5.3	5.9	5.7	4.3	4.7	4.2	5.0
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION	3.1	4.3	4.8	3.5	3.6	2.8	6.2	4.5	4.3	4.5	5.7	5.2	5.3	5.5	3.8	3.8	3.3	4.4
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION	3.7	2.9	3.4	2.2	2.5	2.1	4.5	3.1	3.4	2.9	4.7	5.6	3.7	3.6	2.0	2.8	3.0	3.3
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)	1.4	3.8	3.2	2.8	3.3	2.5	6.3	4.9	4.0	5.3	4.8	4.3	5.3	4.8	4.3	3.9	3.7	4.0
n. MOST WASTED TIME AMONG CRAFTSMEN	1.8	2.8	2.5	2.2	3.0	2.2	7.2	4.4	3.3	3.5	4.7	4.0	7.0	5.5	3.8	2.5	2.5	3.7
o. WASTED TIME WAITING FOR INSPECTIONS	2.5	3.0	3.1	1.9	1.9	1.7	4.6	3.2	2.8	2.8	3.6	3.3	3.3	4.1	1.9	1.9	2.2	2.8
	2.6	3.5	3.4	2.7	3.0	2.6	6.0	3.9	4.0	4.5	5.0	5.0	5.2	5.4	3.3	3.0	2.9	

CHAPTER 4. CONSTRUCTION IMPROVEMENT ANALYSIS

4.1. Data Bases

4.1.1. Buildings

The total of 8 questionnaires as a data base made the Buildings data questionable. The addition of a few more Building questionnaires not previously analyzed could completely change the overall results.

Ratings from Buildings respondents used in the potential improvement question were generally much higher answers and were not as varied in magnitude as other construction divisions. The appearances of 4's, 5's, and 6's predominated.

4.1.2. Light Industrial

The total of 16 questionnaires as a data base made the Light Industrial data base not as suspect as Buildings, but much less reliable than Heavy Industrial or Power. Similarities in many of the problem areas indicate the Light Industrial results are reliable.

4.1.3. Heavy Industrial

By far, the best data base, Heavy Industrial questionnaire results also correllated with each other more than any other intra-division results. More of the same things were said in Heavy Industrial questionnaire results than in other divisions.

4.1.4. Power

Power had the second largest data base and strong, reasonable results. The existence of key problem areas such as piping, electrical, and mechanical equipment on many of the questionnaires signified high reliability in Power answers.

4.2. Project Profiles and Costs

Average project costs differed from $25.2 million for Buildings to a high of $466.6 million for Power projects. Light and Heavy Industrial were middle values with price tags of $118.6 and $188.1 million respectively.

Peak work forces were similiarly distributed with Buildings low at 300 workers, Power high at 1635 workers, and Light and Heavy Industrial at 600 and 896 respectively.

Power projects were heavily union, 81.3%. Heavy Industrial had more open shop projects with only 50.9% union participation. Buildings and Light Industrial were similar in union composition with 61% and 69% respectively.

Significant crafts involved in construction included carpenters, electricians, and laborers for Buildings and Light Industrial. Pipefitters, electricians, and laborers were important crafts in Heavy Industrial and Power. Boilermakers were also significant in Power.

The more expensive construction categories for Buildings and Light Industrial included structure and electrical. Piping was of high value in Light Industrial, Heavy Industrial and Power. Electrical and mechanical equipment also accounted for significant costs in Heavy Industrial and Power.

4.3. Technological Improvement Ratings

4.3.1. Buildings and Light Industrial

High potential categories included special equipment installation, mechanical equipment, and electrical. Vessels were also important in Buildings.

Buildings' high potential indicators included craftsman skill, time and design sensitivity, foreman competence, and problems in material handling. Light Industrial high potential indicators included foreman competence, lead time for scheduling, and craftsman skill.

4.3.2. Heavy Industrial and Power

Piping, special equipment installation, electrical, and mechanical equipment were high potential categories.

High potential indicators included foreman competence, craftsman skill, time and design sensitivity, and lead time for scheduling. Different crafts required were also significant in Power.

4.4. Construction Category Cost Adjustments

To determine potential improvement impact on a construction process, costs must be considered. Cost information by construction category provided the necessary weighting to determine that impact.

4.4.1. Adjusted Construction Categories

Each vertical average indicator number (Table 111-2, bottom margin) was weighted according to the percentage of total construction costs associated with each of the construction categories. The weight factors were taken from the average percent of direct construction costs shown in Table 111-1.

The vertical double average number was multiplied by the weight factor directly to obtain the construction cost adjustments shown in Figure IV-1. The adjustments were relative factors of potential only.

Sample calculation for Earthwork, Buildings division:

4.6	x	4.8	=	22
Table 111-2		Table 111-1		Figure IV-1

Table IV-1 summarizes the information shown in Figure IV-1. The table divided the construction categories into high potential improvement impact, intermediate potential, and low potential.

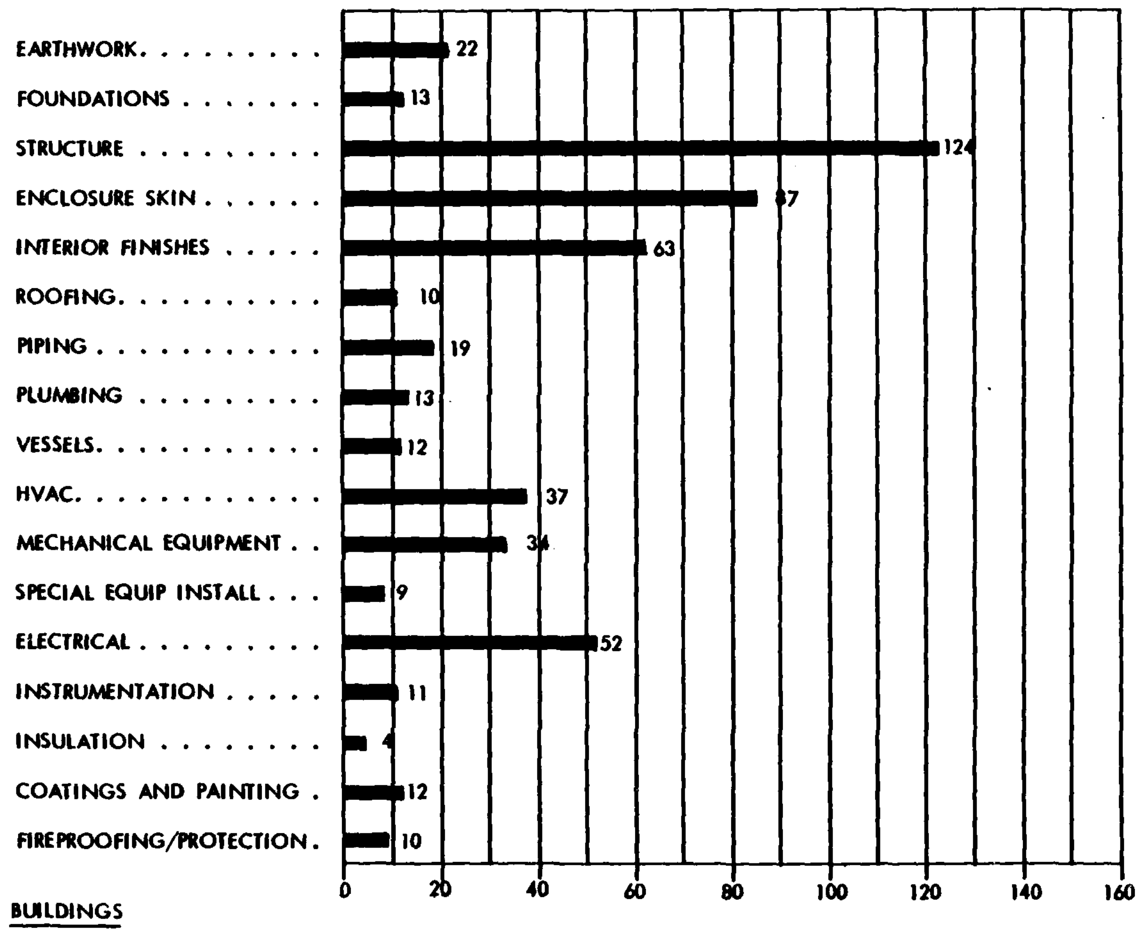

Figure IV -1a Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

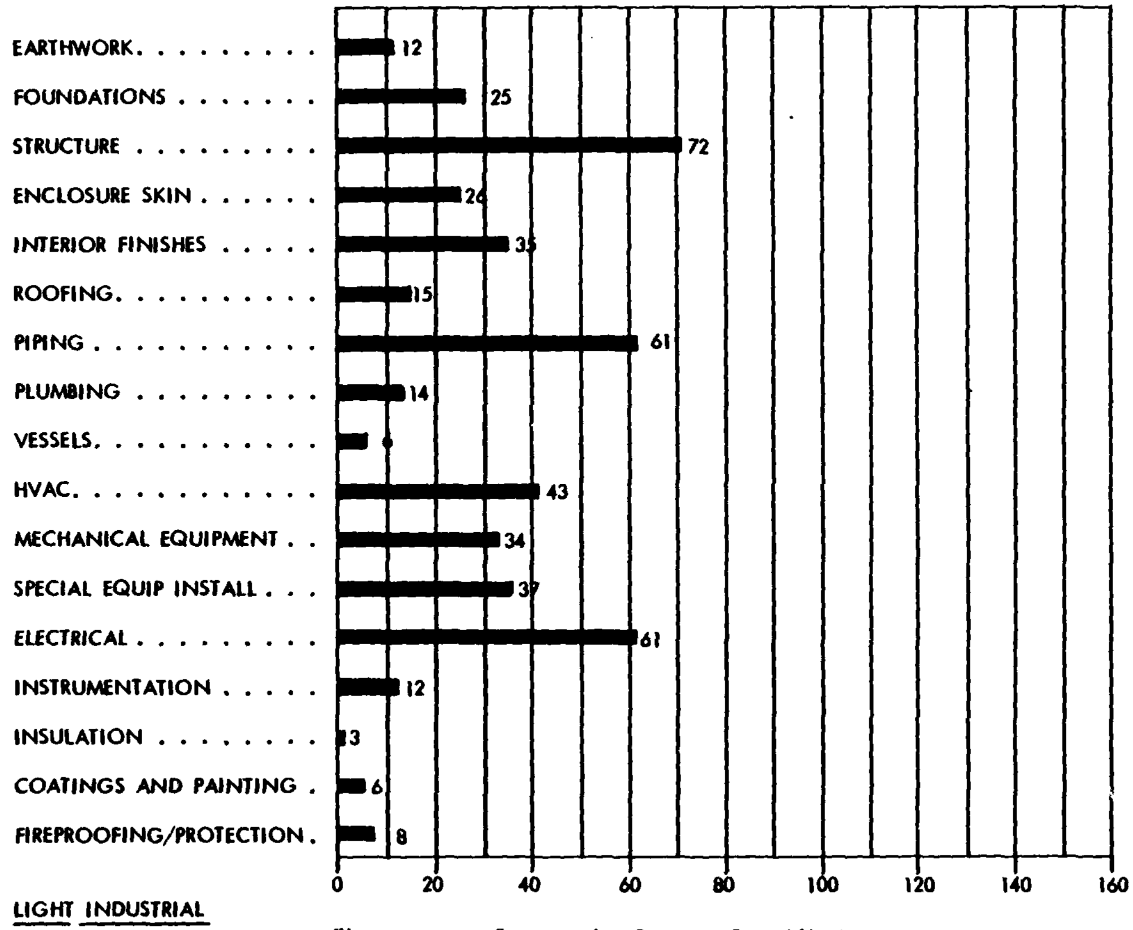

Figure IV-1b Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

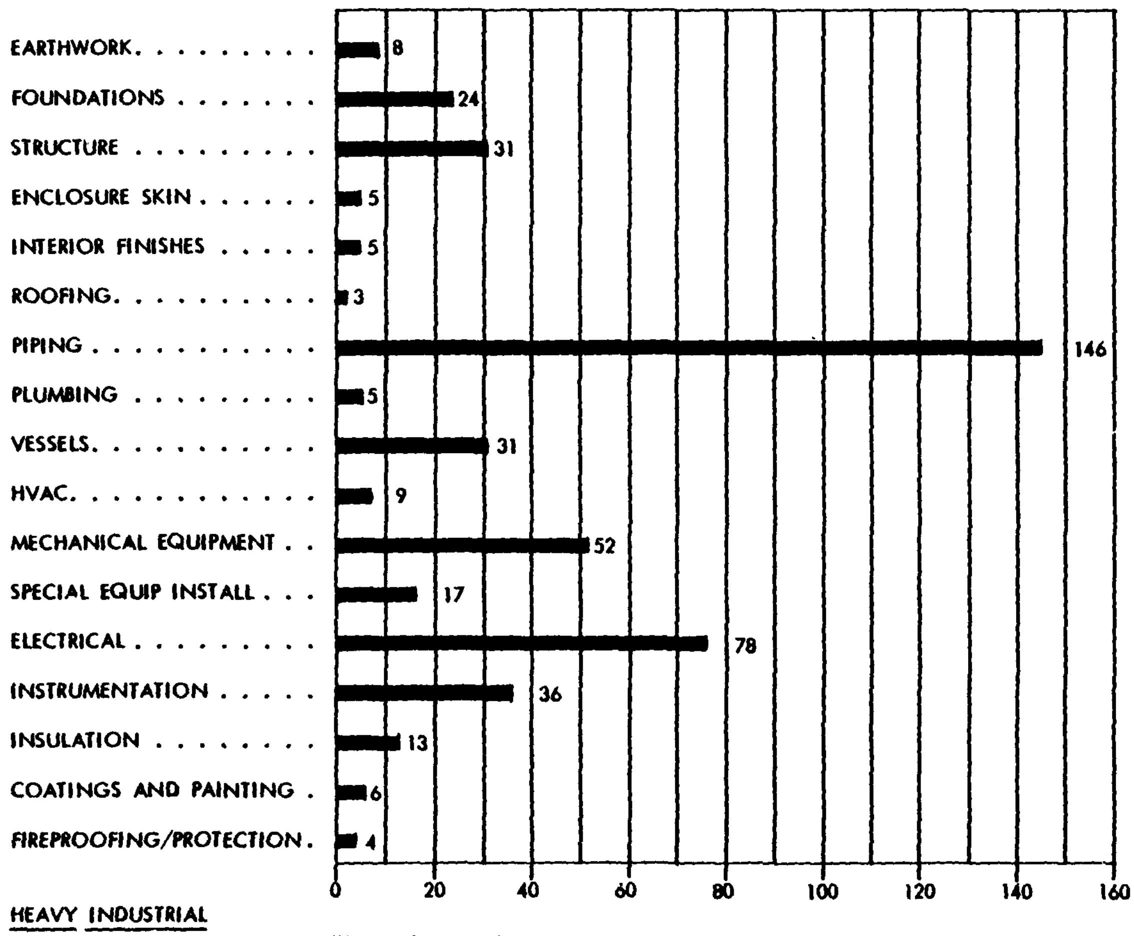

Figure IV-1c Construction Category Cost Adjustments
(Weight Factors from Table III-1, Average Indicators from Table III-2)

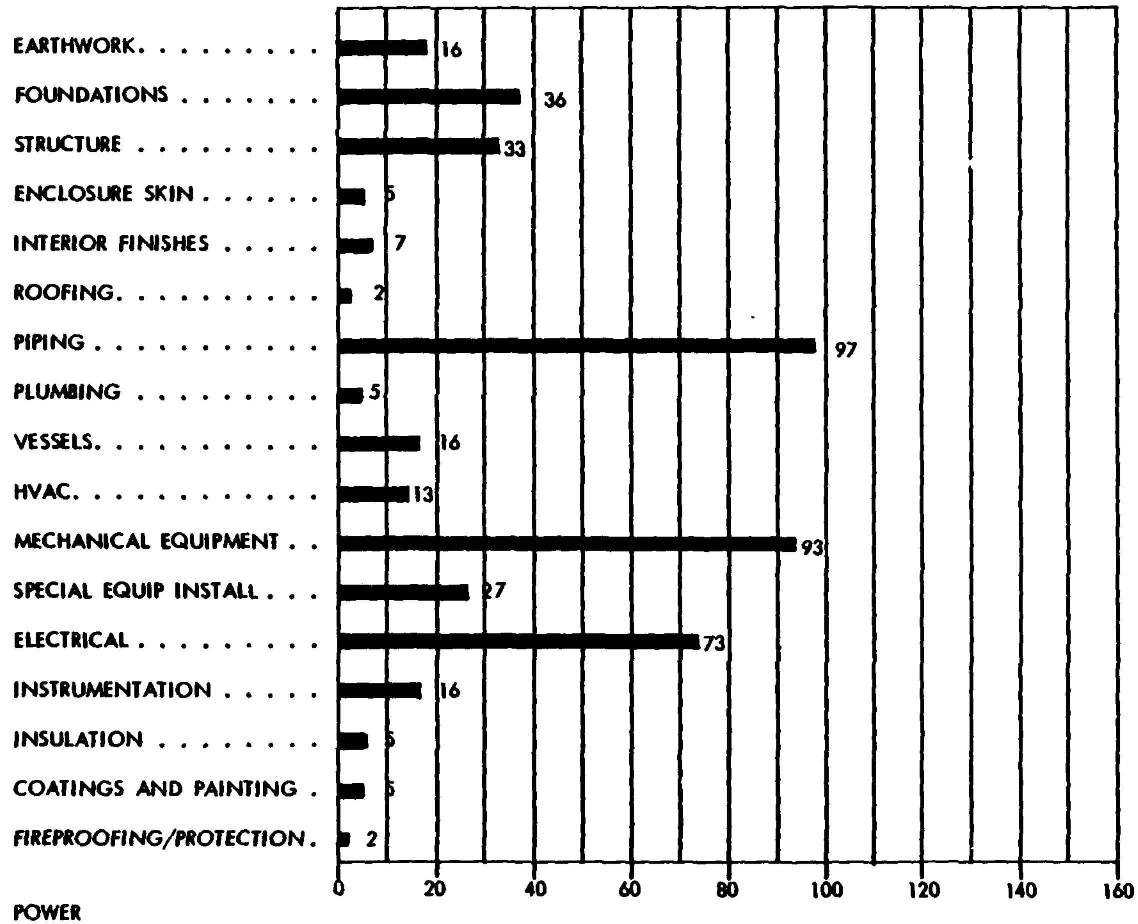

Figure IV-Id Construction Category Cost Adjustments
(Average Indicators from Table III-2, Weight Factors from Table III-1)

TABLE IV-1 CONSTRUCTION CATEGORY TECHNOLOGICAL IMPROVEMENT POTENTIAL
(Potential Number Adjusted for Cost in Parenthesis)

	Buildings	Light Industrial
High Potential	Structure (124)	Structure (72)
	Enclosure Skin (87)	Piping (61)
	Interior Finishes (63)	Electrical (61)
	Electrical (52)	
Intermediate Potential	HVAC (37)	HVAC (43)
	Mech. Equip. (34)	Spec. Equip. Inst. (37)
	Earthwork (22)	Interior Finishes (35)
		Mech Equip. (34)
		Enclosure Skin (26)
		Foundations (25)
Low Potential	Piping (19)	Roofing (15)
	Plumbing (13)	Plumbing (14)
	Foundations (13)	Earthwork (12)
	Coatings & Paintings (12)	Instrumentation (12)
	Vessels (12)	Fire Proofing/Protec. (8)
	Instrumentation (11)	Vessels (6)
	Fire Proofing/Protec. (10)	Coatings & Paintings (6)
	Roofing (10)	Insulation (3)
	Spec. Equip. Inst. (9)	
	Insulation (4)	

(Continued) Table IV-1 CONSTRUCTION CATEGORY TECHNOLOGICAL IMPROVEMENT POTENTIAL

	Heavy Industrial	Power
High Potential	Piping (146)	Piping (97)
	Electrical (78)	Mech. Equip. (93)
	Mech. Equip. (52)	Electrical (73)
Intermediate Potential	Instrumentation (36)	Foundations (36)
	Structure (31)	Structure (33)
	Vessels (31)	Spec. Equip. Inst. (27)
	Foundations (24)	
Low Potential	Spec. Equip. Inst. (17)	Earthwork (16)
	Insulation (13)	Vessels (16)
	HVAC (9)	Instrumentation (16)
	Earthwork (8)	HVAC (13)
	Coatings & Paintings (6)	Interior Finishes (7)
	Enclosure Skin (5)	Enclosure Skin (5)
	Interior Finishes	Plumbing (5)
	Plumbing (5)	Insulation (5)
	Fire Proofing/Protec. (4)	Coatings & Paintings (5)
	Roofing (3)	Roofing (2)
		Fire Proofing/Protec. (2)

Structure and electrical were dominant in Buildings and Light Industrial. Both categories were heavily influenced by the category costs.

Enclosure skin and interior finishes were high potential areas unique to Buildings.

Piping and electrical were important categories in the other three divisions.

Mechanical equipment surfaced as a high potential area in Heavy Industrial and Power.

4.4.2. Adjusted Construction Indicators

In Table 111-2, the 17 average numbers associated with each construction indicator were summed and an average value was taken from the summations. The double average numbers did not take into account the costs of each construction category but treated them instead as equal in weight. The following sample calculation shows how each horizontal double average number became a weighted average. The average was weighted according to the percent construction costs associated with each construction category.

Sample calculation for weighted average for cost estimating, Buildings division:

Category	Rating (Table 111-2)	% Cost (Table 111-1)		
Earthwork	5.6	4.8	=	.269
Foundations	2.3	3.3	=	.076
Structure	3.8	26.9	=	1.022
Enclosure	4.5	15.2	=	.684
Interior Finish	4.5	11.6	=	.522
Roofing	4.8	2.1	=	.101
Piping	4.5	3.4	=	.153
Plumbing	4.3	2.2	=	.095
Vessels	4.3	2.0	=	.086
HVAC	3.8	6.5	=	.247
Mech Equipment	4.0	5.4	=	.216
Spec Equip Install	3.3	1.4	=	.046
Electrical	4.5	8.5	=	.383
Instrumentation	3.5	1.6	=	.056
Insulation	4.5	.8	=	.036
Coatings & Painting	5.3	2.0	=	.106
Fireproofing/ Protect	4.8	2.0	=	.096
				4.194 =
		Table IV-2		4.2

Table IV-2 shows the old horizontal double averages and the new weighted construction indicator improvement potential ratings The old ratings are listed first. The changes were directly attributed to heavy cost weighting or light cost weighting.

Table IV-2 Construction Indicator Improvement Ratings

	Buildings Old New	Light Industrial Old New	Heavy Industrial Old New	Power Old New
Cost Estimating	4.2-4.2	4.5-4.0	4.2-3.8	3.8-3.2
Time Sensitivity	7.4-7.2	4.9-4.8	4.8-4.6	5.0-4.1
Lead Time	5.6-5.6	5.2-5.5	4.7-4.5	4.6-4.4
Proper Materials	4.9-4.4	4.0-3.8	3.6-3.6	3.6-3.2
Rework	5.2-4.3	3.5-3.4	3.2-2.8	3.7-3.4
Communications	5.7-5.8	4.6-4.7	4.0-4.0	4.2-3.7
Materials Handling	6.2-5.6	3.7-3.7	3.3-3.3	3.5-3.3
Prefab Tolerances	5.8-5.7	4.5-5.8	3.6-3.8	3.8-3.9
Different Crafts	3.7-3.2	2.7-2.9	2.7-2.7	2.9-2.8
Foremen Competence	6.4-6.5	6.0-6.0	5.2-5.1	5.0-4.9
Craftsman Skill	7.6-7.7	5.2-5.2	4.9-4.8	4.4-4.4
Required Spec Tools	5.6-5.4	4.2-4.1	3.9-3.8	3.3-3.2
Spt Craft Coord	5.0-5.3	4.4-4.4	4.0-3.7	4.0-3.7
Craftsman Time Waste	4.9-4.9	4.2-4.0	3.9-3.6	3.7-3.3
Inspection Time Waste	4.6-4.0	3.6-3.2	3.2-2.9	2.8-2.7

The new construction improvement potential ratings are also shown graphically in Figure IV-2.

Table IV-3 summarizes the information shown in Table IV-2 and Figure IV-2. The table divides the construction indicators into high potential improvement impact, intermediate potential, and low potential.

Craftsman skill and foreman competence were high priority indicators common to all four divisions.

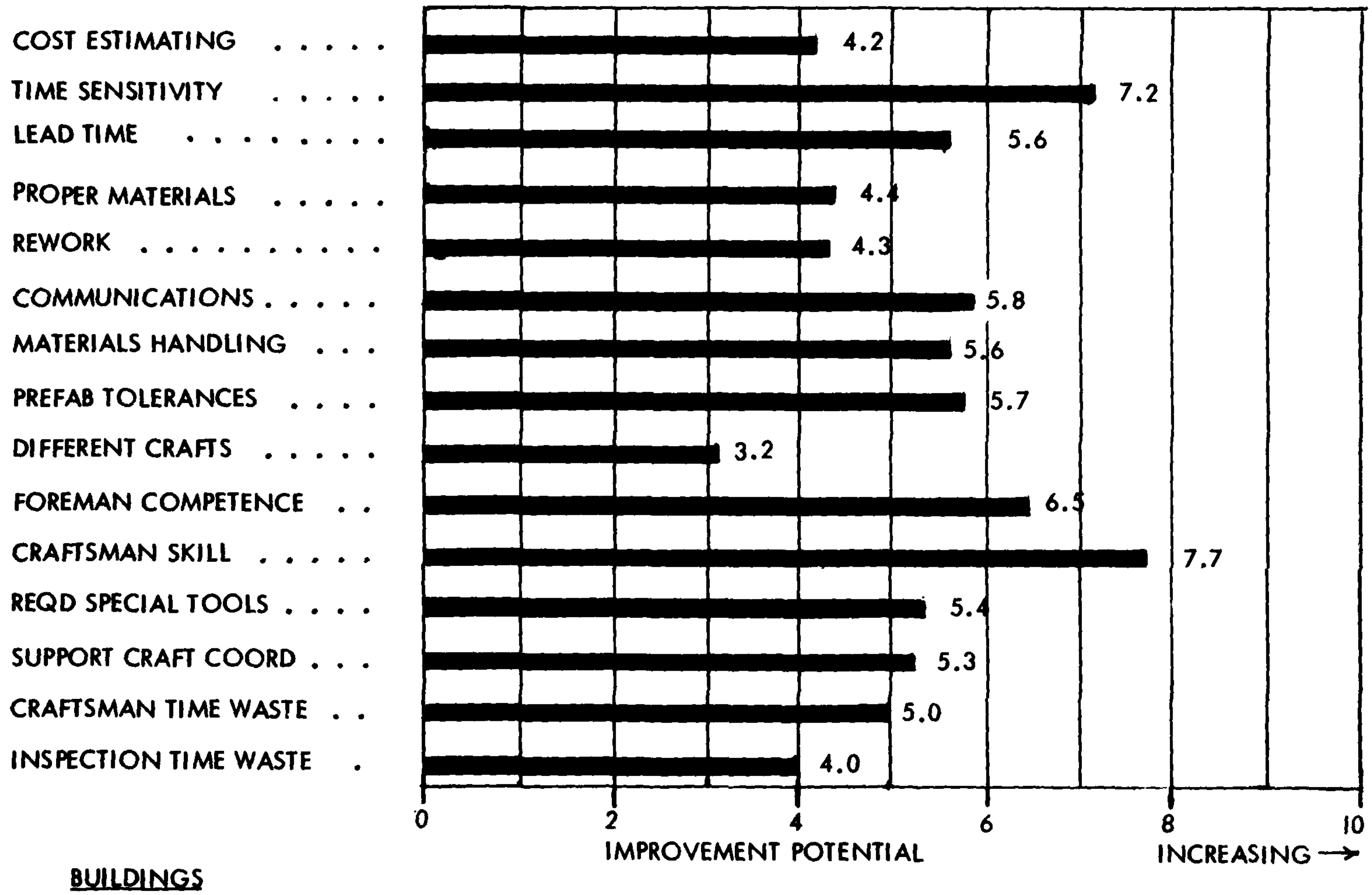

Figure IV-2a Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

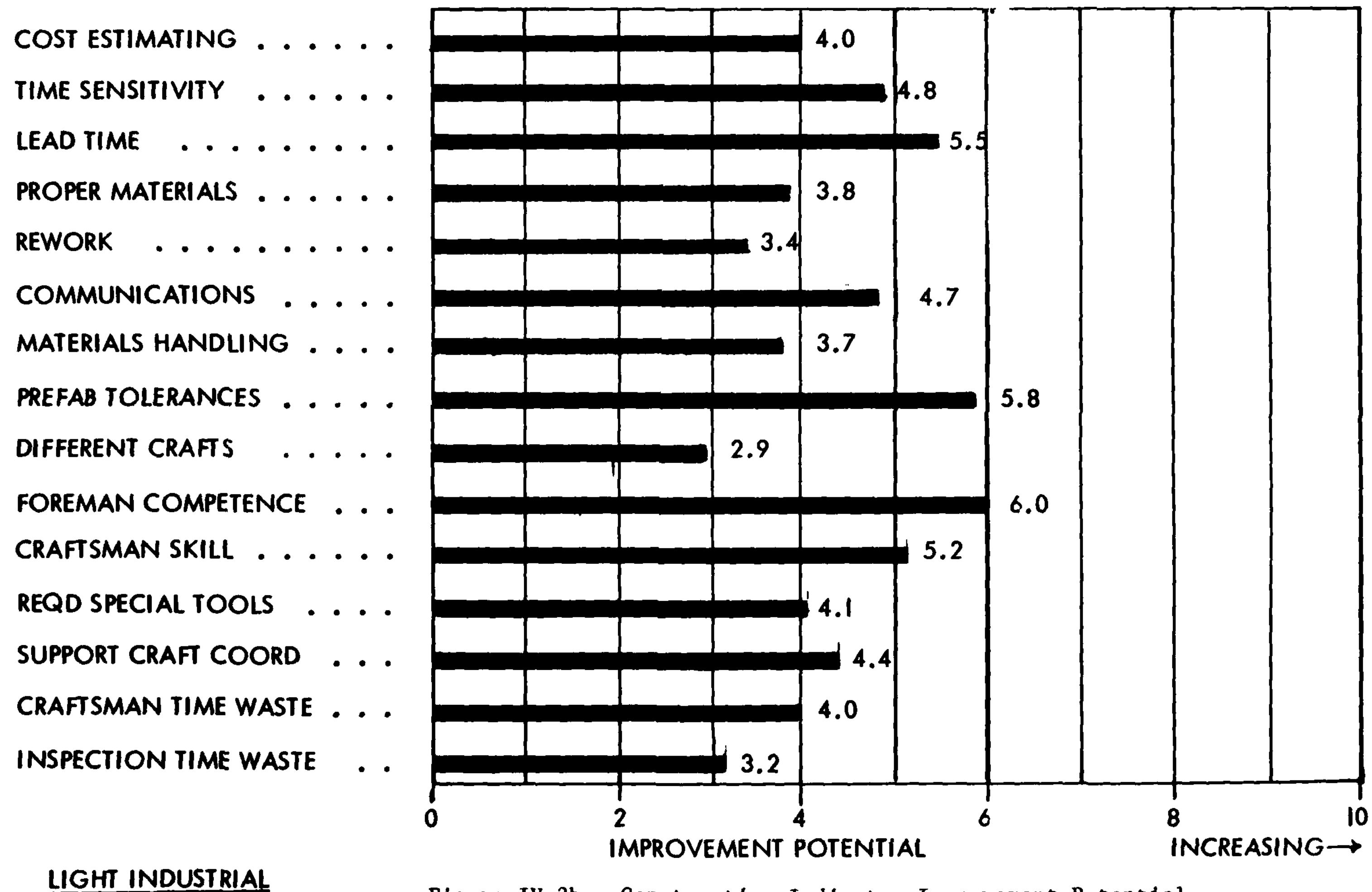

Figure IV-2b Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

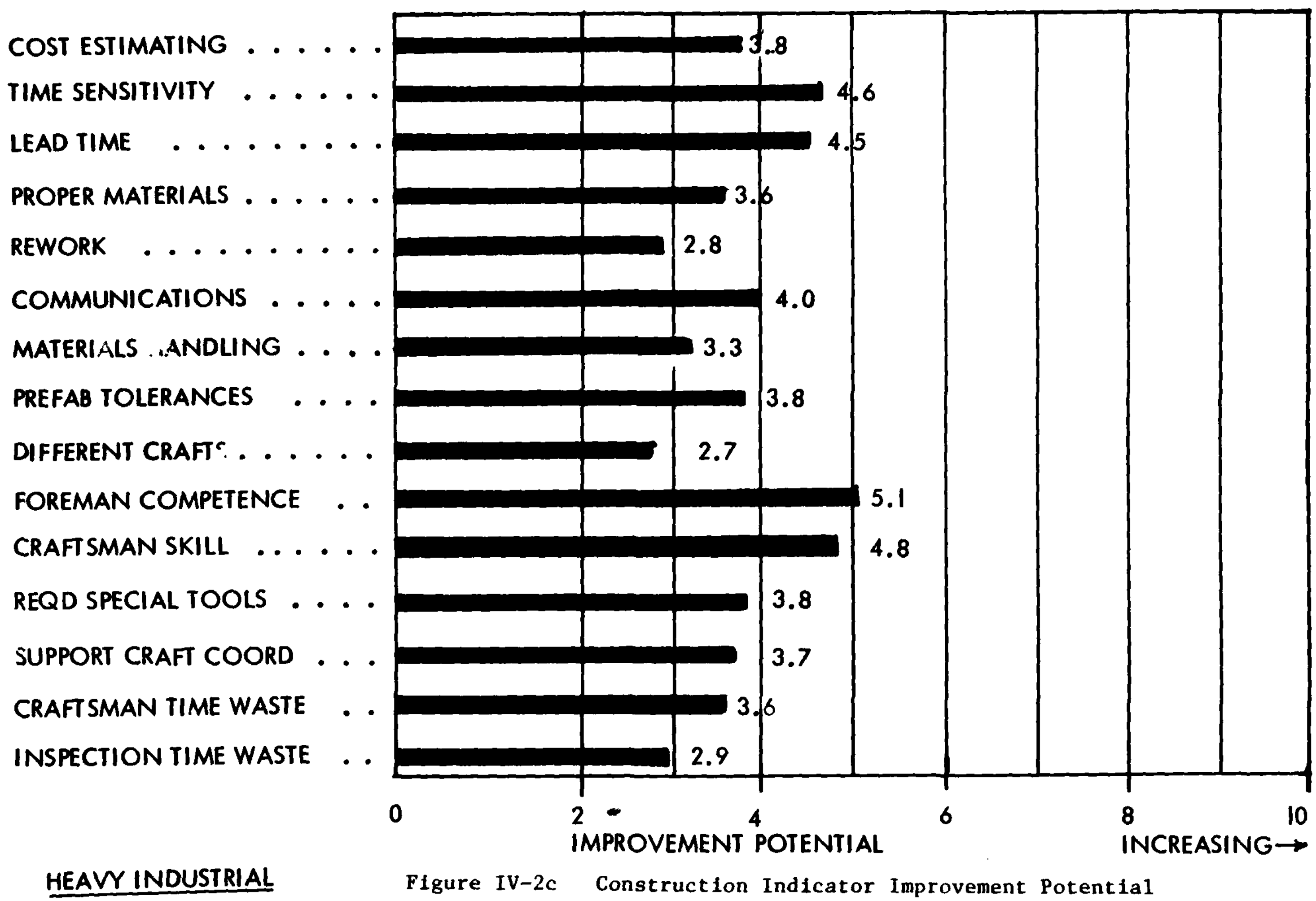

Figure IV-2c Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

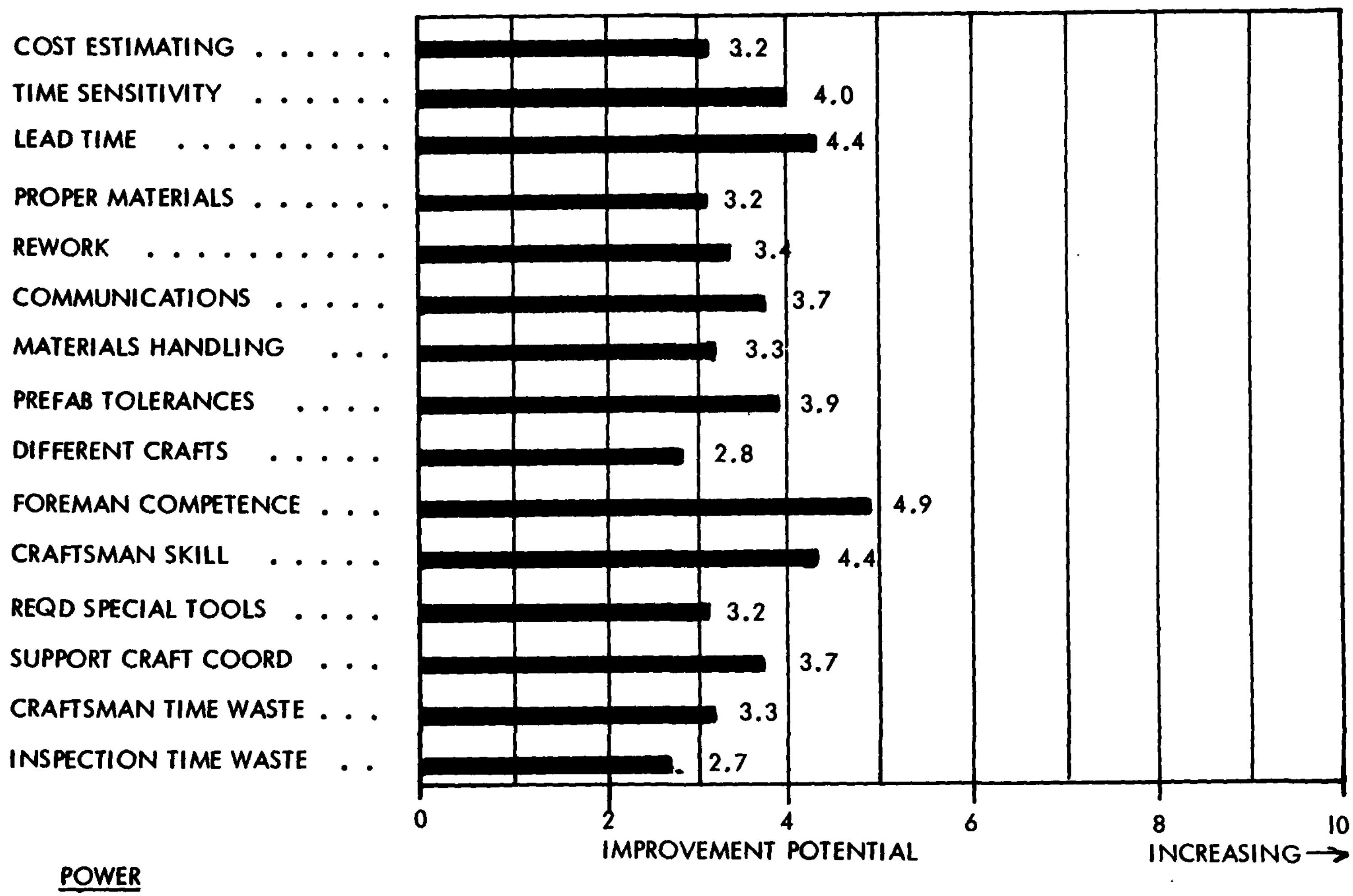

Figure IV-2d Construction Indicator Improvement Potential
(Ratings from Table IV-2, % Cost from Table IV-1)

TABLE IV-3 CONSTRUCTION INDICATOR IMPROVEMENT POTENTIAL
(Potential number from Figure IV-4 shown in parentheses)

	Buildings	Light Industrial
High Potential	Craftsman Skill (7.7)	Foreman Competence (6.0)
	Time Sensitivity (7.2)	Prefab Tolerances (5.8)
	Foreman Competence (6.5)	Lead Time (5.5)
		Craftsman Skill (5.2)
Intermediate Potential	Communications (5.8)	Time Sensitivity (4.8)
	Prefab Tolerances (5.7)	Communications (4.7)
	Materials Handling (5.6)	Support Craft Coord (4.4)
	Lead Time (5.6)	Required Spec Tools (4.1)
	Required Spec Tools (5.4)	Cost Estimating (4.0)
	Support Craft Coord (5.3)	Craftsman Time Waste (4.0)
	Craftsman Time Waste (5.0)	
Low Potential	Proper Materials (4.4)	Proper Materials (3.8)
	Rework (4.3)	Materials Handling (3.7)
	Cost Estimating (4.2)	Rework (3.4)
	Inspection Time Waste (4.0)	Inspection Time Waste (3.2)
	Different Crafts (3.2)	Different Crafts (2.9)

(Continued) TABLE IV-3 CONSTRUCTION INDICATOR IMPROVEMENT POTENTIAL

	Heavy Industrial	Power
High Potential	Foreman Competence (5.1)	Foreman Competence (4.9)
	Craftsman Skill (4.8)	Lead Time (4.4)
	Time Sensitivity (4.6)	Craftsman Skill (4.4)
	Lead Time (4.5)	Time Sensitivity (4.0)
Intermediate Potential	Communications (4.0)	Prefab Tolerances (3.9)
	Cost Estimating (3.8)	Communications (3.7)
	Prefab Tolerances (3.8)	Support Craft Coord (3.7)
	Required Spec Tools (3.8)	Rework (3.4)
	Support Craft Coord (3.7)	Materials Handling (3.3)
	Proper Materials (3.6)	Craftsman Time Waste (3.3)
	Craftsman Time Waste (3.6)	
Low Potential	Materials Handling (3.3)	Proper Materials (3.2)
	Inspection Time Waste (2.9)	Required Spec Tools (3.2)
	Rework (2.8)	Cost Estimating (3.2)
	Different Crafts (2.7)	Different Crafts (2.8)
		Inspection Time Waste (2.7)

Time sensitivity was important to Buildings, Heavy Industrial, and Power.

Lead time was important to Light and Heavy Industrial and Power.

Prefab tolerances were high priority in Light Industrial and intermediate potential in the other three divisions.

4.5. Further Refinements for Analysis of Construction Categories

4.5.1. Project Size Impact

The research group attempted to show impact potential on individual project size by assuming larger projects had more to be gained individually from technological improvement than smaller projects. The average project cost for each construction division determined the size of the project. The savings gained by a large project due to technological improvement was proportional to its average cost. The smaller savings from a smaller project were also proportional to its average cost. The relative factors used to adjust construction categories for project size influence (based on average project cost) are listed in Table IV-4.

Table IV-4 Project Size Adjustments

Construction Division	Average Project Size (Table IV-1)	Adjustment Factors (Relative Ratios Only)
Buildings	$ 25.2 million	.032
Light Industrial	118.6	.146
Heavy Industrial	188.1	.236
Power	466.6	.584

Construction categories multiplied by project size influence gave project size impact factors shown in Figure IV-3.

Sample calculation for Earthwork, Buildings division:

22	x	.032	=	.7
Figure IV-1		Adjustment Factor		Figure IV-3

Power construction categories were more heavily weighted than the other divisions because the average project cost was 2.5 times as expensive as the next most expensive division's average project cost. Buildings were weighted much less due to relatively inexpensive average project costs. Heavy and Light Industrial costs were mid-range in weight. A comparison of the construction categories within each construction division has shown that Power has four of the top five potential categories. Heavy Industrial has the other top potential category.

The top 10 categories adjusted for project size are shown in Table IV-5.

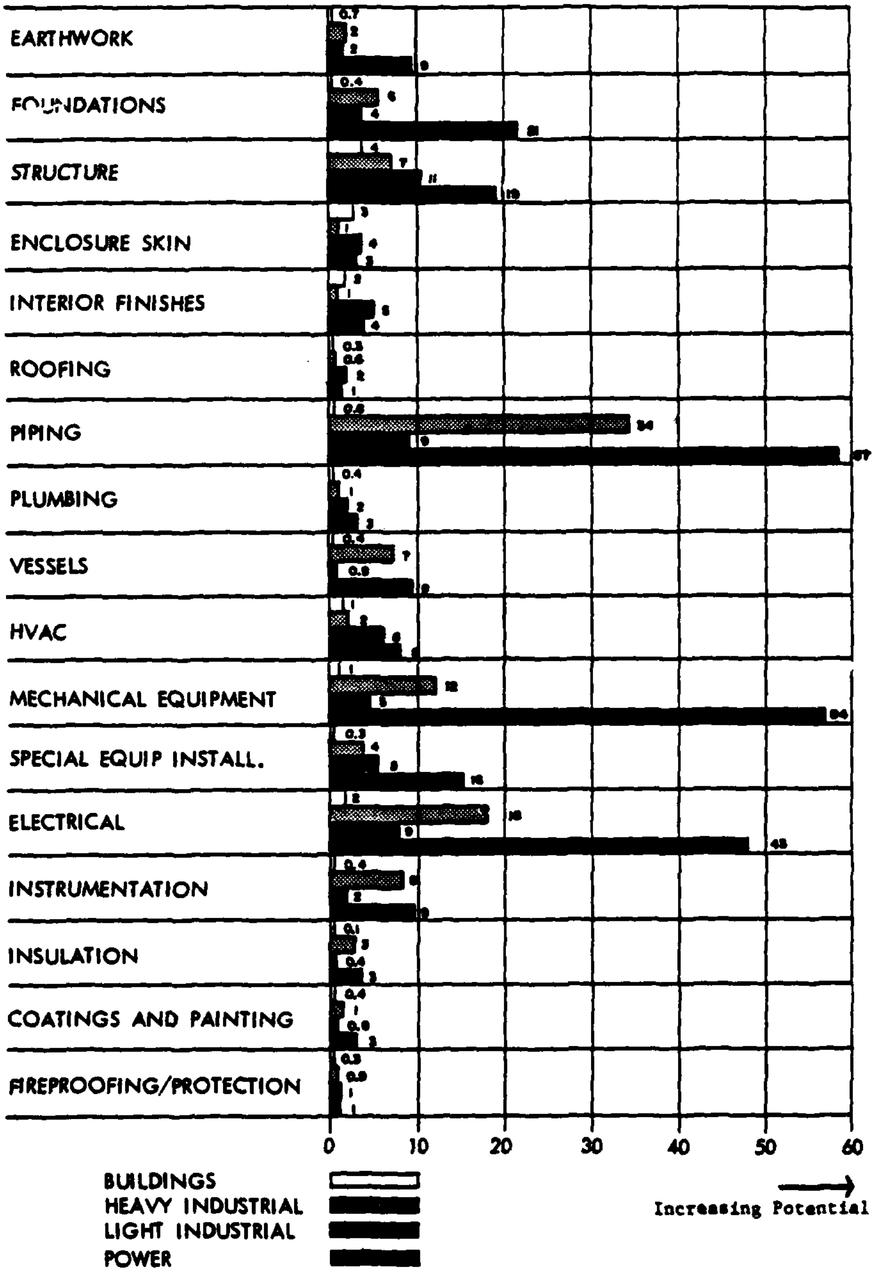

Figure IV-3. Construction Technology Improvement Potential based on Project Size

Table IV-5 Project Size Influence

	Category	Division
Highest Potential	Piping	Power
↑	Mech Equip	Power
	Electrical	Power
	Piping	Hvy Industrial
	Foundations	Power
	Structure	Power
	Electrical	Hvy Industrial
	Spec Equip	Power
	Mech Equip	Hvy Industrial
High Potential	Structure	Lt Industrial

4.5.2. Gross Industry Influence

The values of all Buildings, Light Industrial, Heavy Industrial, and Power construction for 1979 were taken from another CICE project study (5). The total value of each division was expressed as a percentage of the whole. This allowed each division to be compared to the other in terms of relative value. Since the values of Light and Heavy Industrial were not separated in the source information, both divisions were assumed equal.

The basic premise behind gross industry influence assumed construction divisions with more GNP value were indicative of higher total financial savings from increased productivity. The increased productivity would result from technological improvement.

GNP adjustment factors are shown in Table IV-6.

Table IV-6 Gross Industry Adjustments

<table>
<tr><th>Construction Division</th><th>GNP ($Billion)</th><th>Adjustment Factor</th></tr>
<tr><td>Buildings</td><td>69</td><td>.407</td></tr>
<tr><td>Light Industrial</td><td rowspan="2">66</td><td>.213</td></tr>
<tr><td>Heavy Industrial</td><td>.213</td></tr>
<tr><td>Power</td><td>27</td><td>.167</td></tr>
<tr><td></td><td></td><td>1.000</td></tr>
</table>

Construction category cost adjustments (Figure IV-1) were multiplied by gross industry influence adjustments to obtain values for construction technological improvement potential with respect to gross industry influence. The relative weights are shown in Figure IV-4.

Sample calculation for Earthwork, Buildings division:

22	x	.407	=	9
Figure IV-1		Table IV-5		Figure IV-4

Buildings were weighted more heavily than the other three divisions. Buildings represented more than 40% of the total GNP value of all four categories combined. Power was weighted the least with a 16.7% market share. Heavy and Light Industrial were again mid-range in weight.

A comparison of the construction categories within each construction division have shown Buildings to have four of the top five construction categories. Heavy Industrial has the other high priority category.

The top 10 categories adjusted for gross industry influence are shown in Table IV-7.

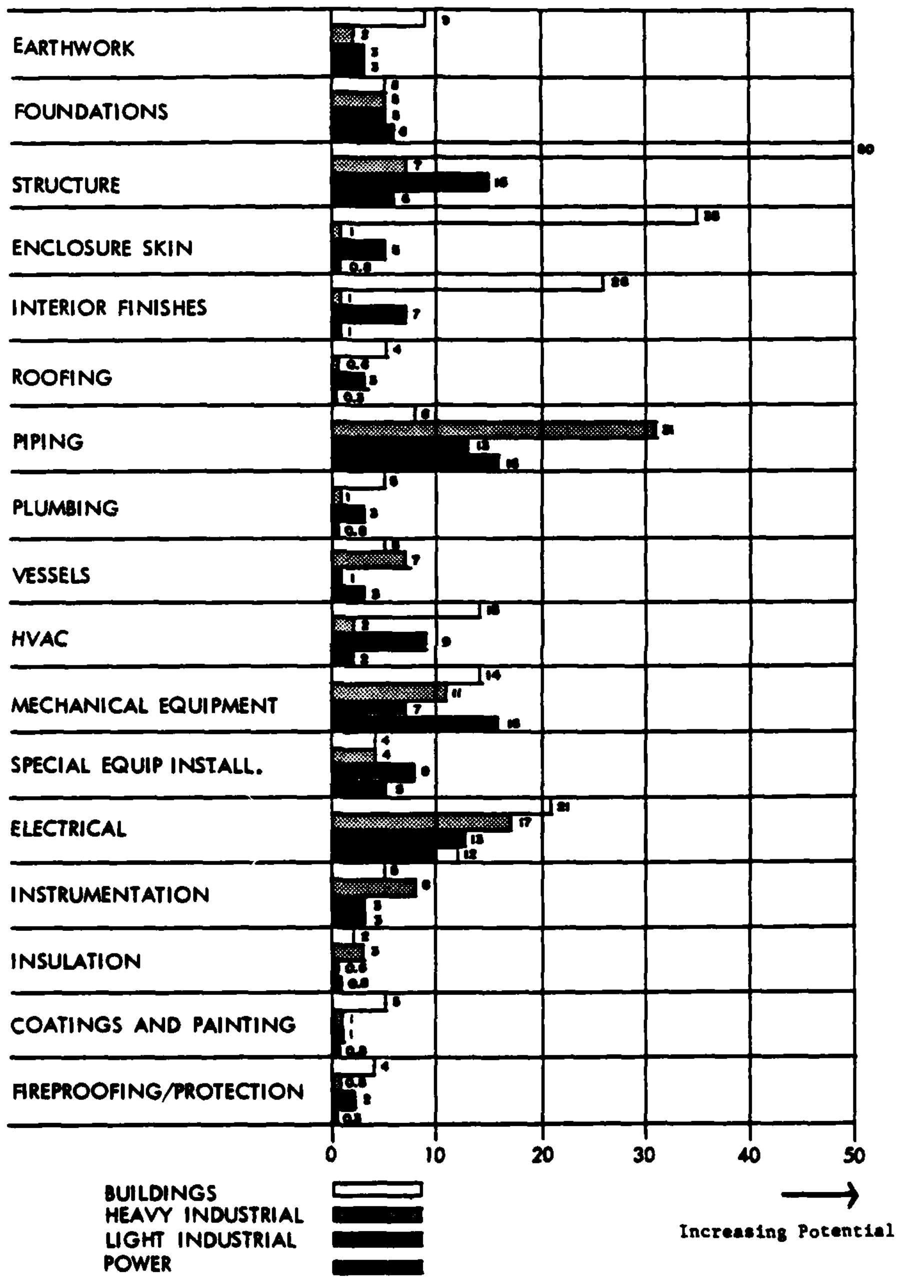

Figure IV-4 Construction Technology Improvement Potential based on Gross Industry Influence

™ ə IV-7 Gross Industry Influence

	Category	Division
Highest Potential	Structure	Buildings
↑	Enclosure Skin	Buildings
	Piping	Hvy Industrial
	Interior Finishes	Buildings
	Electrical	Buildings
	Electrical	Hvy Industrial
	Piping	Power
	Mech Equip	Power
	Structure	Lt Industrial
High Potential	HVAC	Buildings

4.6 Further Refinements for Analysis of Construction Indicators

The construction indicators, previously rank ordered by improvement potential ratings which were weighted by construction category costs, were then prioritized with respect to individual project size and gross industry influence.

The purposes of project size adjustments and gross industry influence were identical to the purposes used for adjustment of construction category prioritization.

Values used to adjust the indicator potential ratings were also the same as the values used for construction category prioritization.

The relative potential ratings with respect to project size are shown in Figure IV-5.

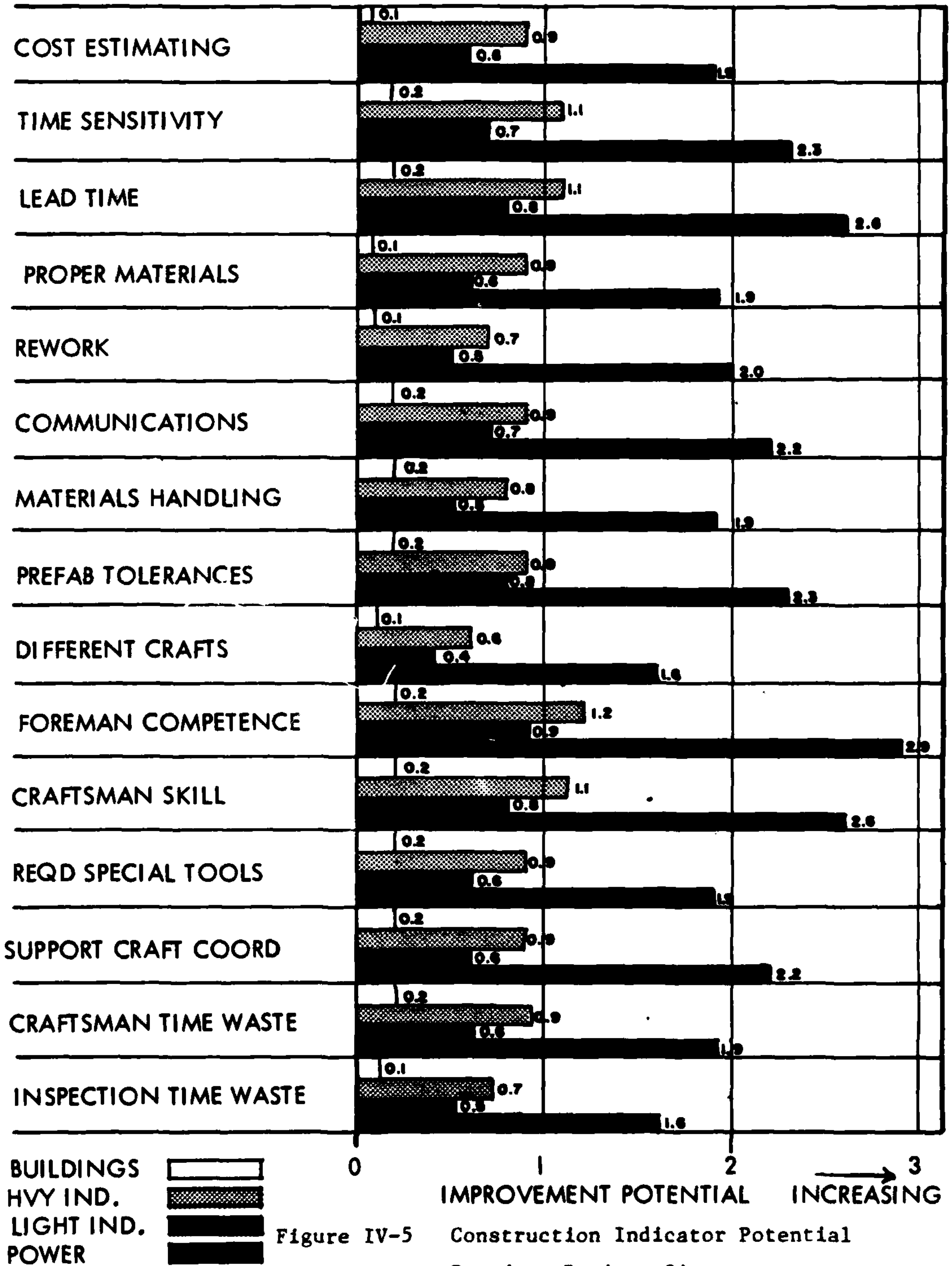

Figure IV-5 Construction Indicator Potential Based on Project Size

Sample calculation for cost estimating, Buildings division:

4.2	x	.032	=	.1
Figure IV-2		Adjustment Factor from Table IV-4		Figure IV-5

In project size influence comparisons, each of the Power division indicators were high priority indicators. Heavy and Light Industrial indicators were mid-range while Buildings indicators were very low.

The relative potential ratings with respect to gross industry influence are shown in Figure IV-6.

Sample calculation for cost estimating, Buildings division:

4.2	x	.407	=	1.7
Figure IV-2		Adjustment Factor from Table IV-5		Figure IV-6

In gross industry influence comparisons, each of the Buildings division indicators were high priority indicators. The other three divisions were mid-range to low potential.

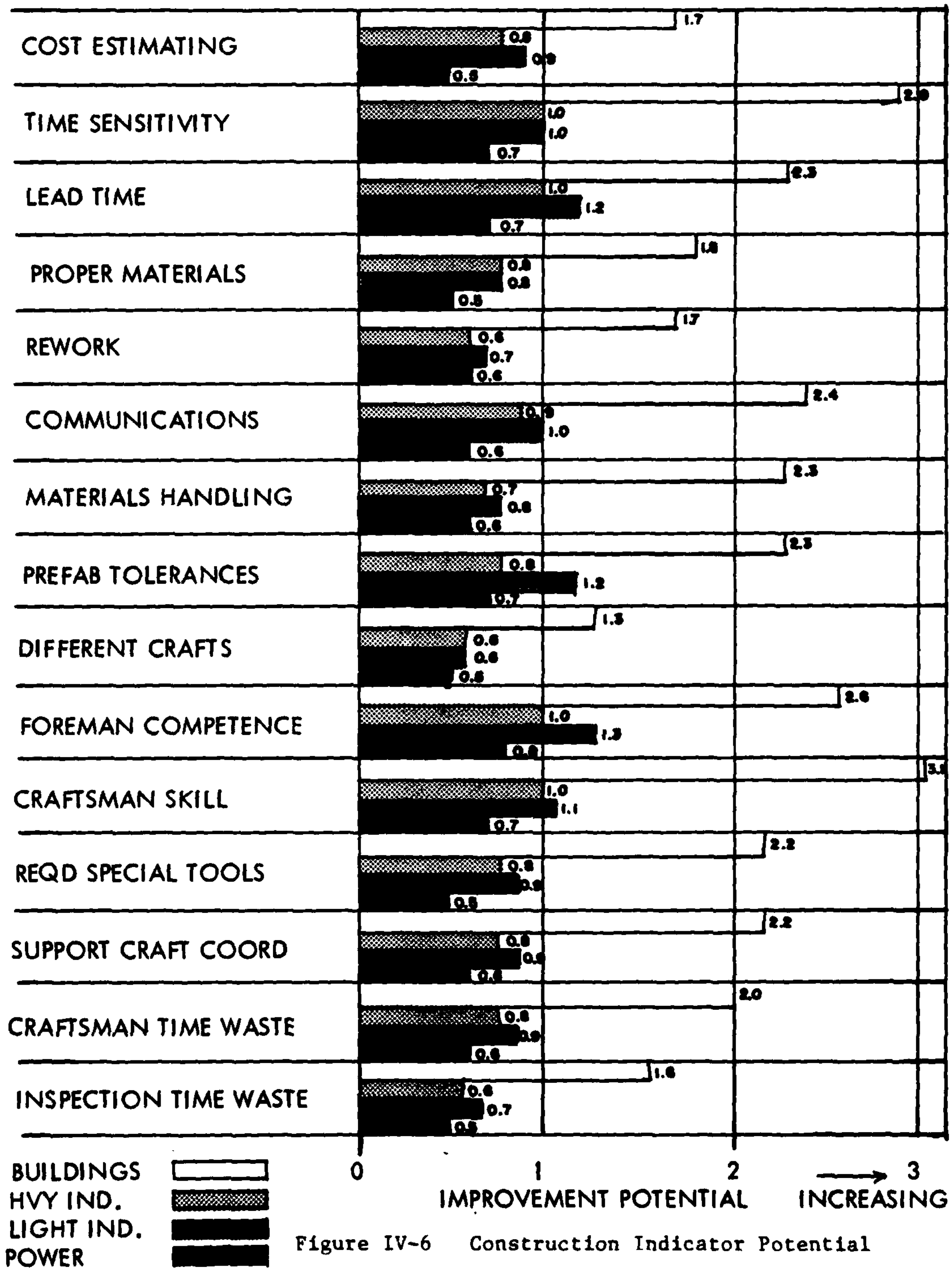

Figure IV-6 Construction Indicator Potential Based on Gross Industry Influence

CHAPTER 5. CONCLUSIONS

5.1. Construction Categories

5.1.1. Construction Category Improvement Potential

Piping and electrical emerged as the common high potential categories. Structure was important to Buildings and Light Industrial. Mechanical Equipment was important to Heavy Industrial and Power. High potential categories are summarized in Table V-1.

Table V-1 High Potential Categories

Buildings	Light Industrial	Heavy Industrial	Power
Structure	Structure	Piping	Piping
Enclosure Skin	Piping	Electrical	Mech Equip
Interior Finishes	Electrical	Mech Equip	Electrical
Electrical			

5.1.2. Impact Potential due to Project Size and Gross Industry Influence

In order to compare overall high priority areas among the divisions, project size influence and gross industry influence were applied to the high potential categories. The results are summarized in Table V-2.

Table V-2 Impact Potential of Categories

	Project Influence	Gross Industry Influence
Highest Potential	Piping-Power	Structure-Buildings
	Mech Equip-Power	Enclosure Skin-Buildings
↑	Electrical-Power	Piping-Hvy Industrial
	Piping-Hvy Industrial	Interior Finishes-Bldgs
	Foundations-Power	Electrical-Buildings
	Structure-Power	Electrical-Hvy Industrial
	Electrical Hvy Industrial	Piping-Power
	Spec Equip-Power	Mech Equip-Power
	Mech Equip Hvy Industrial	Structure-Lt Industrial
High Potential	Structure Lt Industrial	HVAC-Buildings

5.2. Construction Indicators

5.2.1. Construction Indicator Improvement Potential

Craftsman skill and foreman competence were the high potential indicators common to all divisions. High potential indicators were summarized in Table V-3.

Table V-3 High Potential Indicators

	Buildings	Light Industrial
Highest	Craftsman Skill	Foreman Competence
↑	Time Sensitivity	Prefab Tolerances
	Foreman Competence	Lead Time
High		Craftsman Skill

	Heavy Industrial	Power
Highest	Foreman Competence	Foreman Competence
↑	Craftsman Skill	Lead Time
	Time Sensitivity	Craftsman Skill
High	Lead Time	Time Sensitivity

5.2.2. Impact Potential Due to Project Size and Gross Industry Influence

In project size influence comparisons, the high potential indicators were all power division indicators.

In gross industry influence comparisons, the high potential indicators were all Building division indicators.

CHAPTER 6. RECOMMENDATIONS FOR FURTHER STUDY

6.1. Detailed Investigation of Areas with High Improvement Potential

6.1.1. Investigation Methods - Phase 2

High potential categories of construction and indicators of construction effectiveness were identified in the phase 1 research questionnaire. The data was obtained from corporate level executives with broad experience and varied backgrounds.

Phase 2 studies utilize the high priority categories/ indicators identified to narrow the subject matter for further funded research.

The best sources of more detailed construction information are personnel actively engaged in current construction efforts, either working on sites, or supporting from home offices. Their proximity to construction activity makes their information very relevant.

The limited amount of time available and fiscal resource limitations will restrain the efforts of the research team in gathering information. The limited research resources can best be utilized by investigating only the high priority areas in an organized manner.

The research group should endeavor to obtain a national cross section of sites within each construction division investigated to lend legitimacy to the Phase 2 studies.

Information collection through combinations of interviews and questionnaires has proven successful in past construction research studies. That successful precedent should be applied to the present study.

Selection of persons to be interviewed must depend on subject material in two different methods. The results of question 5 lend themselves to organization of the subject material in two different methods.

METHOD ONE:

Each interview session would focus on one high potential category of construction such as piping, electrical work, and structural assembly. The questions would use high potential indicators of construction effectiveness to deal with specific aspects of the category investigated.

The one category of focus of each interview session would enable researchers to interview foremen, general foremen, and craft superintendents as well as field engineers. Those individuals are easily accessible on construction sites and have experience in their backgrounds that would be of use in their answers. Since the crafts are organized along

category of construction lines, one person could give complete information at an interview. With one hour interviews, researchers could research at least eight different crafts in a normal working day. The interviews could be conducted with minimal interference of work on the site. Only one supervisor would be absent from his place of duty in a time period.

METHOD TWO:

Each interview session would focus on one high potential indicator of construction effectiveness such as craftsman skill, foreman competence, necessary lead time, or time sensitivity to design. The questions would use the categories of construction to deal with specific aspects of the indicator examined.

The indicator investigated would necessitate group interviews with several crafts present, or would require audience with senior field engineers, project managers, and profit center managers in home offices. Such upper level managers would supervise activities associated with each indicator. The activities span several crafts and would be very broad in scope.

6.1.2. <u>Advantages of Method One</u>

1. Method one involves one on one interviews with personnel readily accessible for interviews. Similar studies have been conducted in the past with success.

2. Foremen and craft superintendents are closest to the actual construction activity and can give timely information very exacting in nature.

3. Categories of construction as opposed to indicators of effectiveness are better differentiated and serve as understandable subdivisions for research data organization and presentation.

4. The research team believes the categories of construction are complete and accurate. The indicators were intuitively derived without prior extensive research and are assumed complete.

6.1.3. <u>Advantages of Method Two</u>

1. Interviews with groups are effective at times. The group members stimulate each other with ideas that build upon themselves.

2. Similiarities from indicator impact on different crafts could more easily be detected in group interviews.

3. Interviews with higher level managers produce information based on broad perspectives and experience in related areas. Often, the information is multifacited and interfaced.

4. The thrust of each indicator lends itself to improvement suggestions. The interview purpose is more easily satisfied.

6.1.4. Method Recommended: Method One

Principle reasons:

1. The interviews are more easily controlled.

2. Interviews are more easily scheduled with minimal job interference on the sites.

3. Interview questions are more easily formulated and understood.

4. Results are better analyzed and presented.

6.2. Indicator Accuracy and Completeness

The 15 indicators on construction effectiveness used in the phase 1 questionnaire were intuitively formulated by the research team without prior extensive investigation. They were assumed to be complete for purposes of the study.

Much understanding of the construction process could be gained by evaluating the "best guess" indicators for accuracy of completeness. Possible problem areas of construction ineffectiveness could be combinations of the postulated indicators or results of criteria not yet formally recognized.

Possible also would be efforts to canvas other CICE results in areas such as Labor Effectiveness, Labor Supply and Training, and other construction technology studies to check the indicators used in question 5.

6.3. Similar studies in Other Construction Divisions

The methods of research applied in phase 1 could be easily modified for other construction divisions such as highways, seaport construction, dams, or other large, civil engineering works. Most of the other divisions fall in the public sector of construction.

APPENDICES

APPENDIX A. CONSTRUCTION TECHNOLOGY SURVEY

CONSTRUCTION TECHNOLOGY SURVEY

The Business Roundtable is conducting a major effort to improve construction through the Construction Industry Cost Effectiveness (CICE) Project. The Business Roundtable has given our group the opportunity to conduct a study to identify areas of potential construction improvement through technology.

Our approach is to conduct two surveys. The first uses a questionnaire (enclosed) to provide information for areas of future specific investigation. The questionnaire is being sent to knowledgeable, corporate level managers who can provide that information. The second survey, which will be done this summer, will be at the project level on actual sites, and will involve both questionnaires and interviews. Your answers to this questionnaire will help us to identify and prioritize those areas for this summer's activities.

The questionnaire is divided into four parts. The first part asks your background, experience, and your name, should we need to contact you for explanation of your answers. The next part asks about your present use of integrated construction technology. The third part asks you to rate different work categories per the instructions at the beginning of that part. The last question solicits your help in our summer investigations.

The questionnaire is designed to be simple and time effective. We realize you have probably been involved in other CICE studies and appreciate your giving us your best efforts in our project also.

Please return the questionnaire to your designated company representative and contact him if you have any problems. If he can not help, we would be glad to assist you. Contact one of us at The University of Texas at Austin: Dr. Richard Tucker, Stephen Sheppard, or Bryan Tucker at (512) 471-1733.

Cordially yours,

Richard L. Tucker, P.E.
Professor

CONSTRUCTION TECHNOLOGY SURVEY

1. Give your name, title, address, *brief* description of experience

   Name ______________________________

   Title ______________________________

   Address ______________________________

   ____

   ____

   Phone ______________________________

   Experience ______________________________

   ____

   ____

   ____

   Is your firm owner or contractor? (circle)

CONSTRUCTION TECHNOLOGY SURVEY

2. Select factors that describe typical construction projects with which you have been involved in the past five years.

A. Category of Construction:

☐ Buildings (non-residential)

☐ Heavy Industrial (basic industry, chemical plants, etc.)

☐ Light Industrial (food plants, assembly plants, etc.)

☐ Power Generating

B. *Project Construction Cost:*

☐ less than 10 million ☐ 50–100 million

☐ 10–50 million ☐ 100–500 million

☐ greater than 500 million

C. Size of Peak Work Force (Manual):

☐ less than 100 ☐ 500–1000

☐ 100–500 ☐ greater than 1000

D. Give the percentage of projects which are union:

☐ 0% ☐ 50–99%

☐ 1–50% ☐ 100% Union

E. Identify the crafts listed below which represent the labor makeup on your typical projects:

% Craft	% Craft
___ Boilermakers	___ Laborers/Helpers
___ Carpenters	___ Painters
___ Cement Finishers	___ Pipefitters
___ Electricians	___ Riggers
___ Equipment Operators	___ Roofers
___ Insulators	___ Teamsters
___ Instrument	___ Welders
___ Ironworkers	___ List Others: ___________
___ Masons	___________
___ Millwrights	___________
	100% Total

CONSTRUCTION TECHNOLOGY SURVEY

3. Estimate the relative percentages of direct construction costs (at the site) of your typical projects which are associated with the following categories (ignore the costs of special equipment; this question relates to labor and materials associated with installation and erection):

Category	Approximate % Cost
Civil	
Earthwork	________
Foundations	________
Structure	________
Enclosure Skin	________
Interior Finishing	________
Roofing	________
Mechanical	
Piping	________
Plumbing	________
Vessels	________
HVAC	________
Mechanical Equipment	________
Special Equipment Installation	________
Electrical	________
Instrumentation	________
Insulation	________
Coatings and Painting	________
Fireproofing/Fire Protection	________
TOTAL:	100%

CONSTRUCTION TECHNOLOGY SURVEY

4. The term INTEGRATED CONSTRUCTION TECHNOLOGY refers to the practice of having construction personnel work closely with the design team during the development and design phases of a project. The purpose of this interface is to integrate the construction team's knowledge into the design effort. The project will then be more efficient to construct.

Analyze your firm's use of integrated construction technology and answer the following:	ALWAYS	FREQUENTLY	OCCASIONALLY	SELDOM	NOT USED
A. Do you integrate construction technology in planning and project design.	☐	☐	☐	☐	☐
B. Does your company have a formalized/standardized system to integrate construction in the project process.	☐	☐	☐	☐	☐
C. How often does your company save planning costs through use of integrated planning.	☐	☐	☐	☐	☐
D. How often does your company save construction costs and time through use of integrated planning and design.	☐	☐	☐	☐	☐
E. Does your firm separate engineering from construction during project development.	☐	☐	☐	☐	☐
F. Do you use integrated processes on a fixed price project.	☐	☐	☐	☐	☐

	greater than 20	20–15	15–10	10–5	less than 5
G. What percentage of project hard dollar costs are saved by utilizing integrated processes.	☐	☐	☐	☐	☐

H. List other benefits derived from using integrated construction technology. ____________________

I. What commercial contracting methods do you use for design, engineering, and construction. ____________________

CONSTRUCTION TECHNOLOGY SURVEY

5. The following question is intended to provide insight into opportunities for technological improvement. Use your past experience on projects as a basis for answering each question. After each question, consider the civil, mechanical, and other categories listed, and rate each category on a scale of 1–10 with the following meanings:

10—causes problems; a matter of concern; a priority area for technological improvement.

1—a relatively stable area; not an obvious area for technological improvement.

Leave blank any area which does not apply to your typical project.

NOTE: The numbers 1–10 are relative ratings. Thus, the same number can be assigned to more than one item. Write the number selected in the appropriate box, whole numbers only.

Rate the work categories in terms of:	CIVIL					MECHANICAL						OTHERS					
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Installation	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection
a. DIFFICULTY IN ESTIMATING COSTS																	
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN																	
c. NECESSARY LEAD TIME FOR SCHEDULING																	
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)																	
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS																	
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS																	
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION																	
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY																	
i. NUMBER OF DIFFERENT CRAFTS REQUIRED																	
j. DEPENDENCE ON FOREMEN COMPETENCE																	
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION																	
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION																	
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)																	
n. MOST WASTED TIME AMONG CRAFTSMEN																	
o. WASTED TIME WAITING FOR INSPECTIONS																	

CONSTRUCTION TECHNOLOGY SURVEY

6. The next phase of this survey will likely be conducted at the project level and will include interviews with Project Managers and their key assistants. Will you please identify below those projects in your company which you feel would provide useful information and be available for interviews in the July–August, 1981, time frame?

PROJECT A Name of Project ________________

Address ________________

Project Manager ________________

Phone Number ________________

PROJECT B Name of Project ________________

Address ________________

Project Manager ________________

Phone Number ________________

PROJECT C Name of Project ________________

Address ________________

Project Manager ________________

Phone Number ________________

We welcome your comments as necessary. If applicable, refer to the specific question concerned:

____

____

____

____

____

END OF SURVEY

APPENDIX B. COMPANIES CONTRIBUTING INFORMATION

1. Contractors

Austin Company (Cleveland)	Ebasco (New York)
Barton Malow	Fluor Constructors
Bechtel Petroleum	Frank J. Rooney
Bechtel Power	J. A. Jones
Bellows Construction	Morrison-Knudsen
Burns and Roe	Ortloff Co.
Daniel Construction	Pankow (Hawaii)
Dravo Corporation	Ray McDermott
Ebasco (Houston)	Voss, Intl.

2. Owners/Power

ALCOA	Georgia Power
American Electric Power	Monsanto
Amoco	Owens Corning Ware
Caterpillar	Phillips Petroleum
Commonwealth Electric	Proctor and Gamble
Dow Chemical	Texaco
Dupont Chemical	Union Carbide

3. Designers

Black and Veatch	J. E. Sirrine
CH2M Hill	Sargeant and Lundy

APPENDIX C. TIME SCHEDULE

Outline of Research by U. of Tex., Investigation by CICE	October-December 1980
Background Research	January-February 1981
Preparation of Part 1 Questionnaire	March-May 1981
Distribution/Collection of Part 1 Questionnaires	June-August 1981
1st Estimate of Questionnaire Results	July 1981
Data Reduction/Interim Reports for Part 1 Results	September-November 1981
Final Report	December 1981

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